TOPICS OF THE MONTH

Concentrating on corrosion

IN this issue we bring together the latest information about various means of combating corrosion from the point of view of the designer of chemical and allied plant. We hope that these articles and notes will serve as a useful guide and also as a stimulant to more purposeful thinking about corrosion at the design stage. Of all engineers, the chemical engineer needs less reminding of the subject of corrosion. Yet it is precisely because he is obliged to consider corrosion resistance as being more important than anything else, including cost, that the chemical engineer needs to keep fully alive to the advantages of various materials of construction and to know not only how corrosion resistant they are but also how they compare for a particular application when cost and also physical and other properties are considered as well. New materials of construction and new variations on older materials, as well as new fabricating techniques, are constantly being developed, but progress can be made in the right direction only if the engineers who use these materials and techniques examine all possible alternatives, instead of accepting them unquestioningly, for each new application.

Corrosion Convention

WE are by no means alone in giving special attention to corrosion this month, for on October 15 Sir Hugh Beaver, K.B.E., president of the Institution of Chemical Engineers, will propose a toast to " The Fight Against Corrosion " at a special dinner in London as part of National Anti-Corrosion Week. During that week there is a two-day Corrosion Convention as well as the three-day Exhibition of which we give details in this issue. Both are organised by our associate journal *Corrosion Technology*. Dr. E. H. T. Hoblyn, M.B.E., director of the British Chemical Plant Manufacturers' Association, will be chairman at one of the four technical sessions, while others will be Dr. E. S. Paice, head of plastics and resins, Shell Chemical Co. Ltd., Dr. R. S. Thornhill of I.C.I. Alkali Division and Dr. W. F. Higgins of Magnesium Elektron Ltd.

Among the subjects to be discussed are, to mention only a few: ' Protection of Plant and Equipment in the Petroleum and Chemical Industries,' by Dr. H. B. Footner of Shell Petroleum; ' Vinyl Resins in the Construction of Chemical Plant,' by W. E. Martin of BX Plastics; ' Selection of Corrosion-resistant Metals and Alloys,' by J. B. Cotton of I.C.I. Metals Division; and other subjects of vital importance in the chemical and allied fields. This is a conference which should have a resounding effect in all industries where corrosion has still to be conquered.

Coking in the U.S.

THERE is considerable benefit to be derived from the investigations of the British coke-oven experts just ending a four-weeks' tour of coke-oven plants, iron and steel works and research centres in the United States. The last visit of a similar nature took place in 1947, and obviously there have been one or two innovations in the American coking industry since then which might well have a bearing on the design of coke ovens for British conditions.

However, it should be borne in mind that in America there is not the same urgent need as in Europe to build coke ovens suitable for carbonising the lower-grade coals, and this fact has to be carefully weighed in making any comparisons.

The delegation has been formed by the British Coke Research Association, and left Britain on September 20. As well as the general design of coke-oven and ancillary plant the delegation will consider the question of correlation with the iron-making process, and also the general economic position of the coking and by-product industry. The main line of research work and thought in America devolving from the treatment of coal and coke will also be examined, while perhaps the most interesting results of the tour will come from a study of the possibilities of developing new methods of making iron and coke.

Computer controls fractionating column

RAPID and automatic solution of calculations for controlling a fractionating column by the use of a digital computer has been the subject of research work in the United States and equations have been developed for the fractionation process which, when solved repeatedly, yield an appropriate feed tray, an economical reflux rate, and the amount of heat input for a column top-product of specific composition.

A computer-controller has been constructed for demonstration purposes and the selected feed tray, the reflux rate, and the rate of heat input are displayed on a simulator board. Because of its slowly varying disturbances, the initial application of this computer-controller will probably be to instruct the operator in resetting conventional controllers, using input data obtained by conventional means. To simplify operation the input data may be inserted in analogue form just ahead of analogue-to-digital converters. The required heat input, the selected feed tray, and the reflux rate would be read from the display panel by a human operator, who then would control the process accordingly.

On-line continuous control can be obtained by connecting all measuring instruments directly into the computer, which determines the operating conditions,

and sends signals to the feed tray selector, heat input, and reflux rate actuators. Composition measurement of the feed mixture may be obtained, for instance, by measuring the infra-red absorption of a sample of the mixture. A flow meter determines feed rate.

Describing this development in *Control Engineering*, 1957, **4** (9), 144, Mr. H. L. Engel points out that even a relatively low-speed digital computer can perform in a few seconds the calculations necessary for controlling a binary fractionating column. However, because of the slow disturbances, the calculations are done infrequently, and a large amount of computer time is not used. This time can be shared by a number of fractionating columns, with the computer programme altered automatically for individual column conditions and efficiency.

Fuel efficiency raises productivity in chemical industry

NO firm, using trucks to transport material from one part of the works to another, would dream of scrapping them after they had been unloaded once. Yet this is exactly what most firms do with heat. It is exceptional to bother whether the heat exhausted from one stage in the process cannot be harnessed in another stage, instead of being wasted. The greatest fuel savings that are now being recorded result from just such searches for means of putting waste heat to use.

In other cases much can be done to eliminate unnecessary heat wastage, as was found with a British firm of plastics manufacturers who approached the National Industrial Fuel Efficiency Service for advice on rationalising their heating arrangements. They thought it should be possible to close down a small oil-fired boiler, which generated steam, by transferring the load to a coal-fired Lancashire boiler, which served a high-pressure hot-water system. To start with, it was found that 49% of the steam was running to waste. By replacing a single steam trap, and other maintenance work, a saving of 12,600 gal. p.a., or 56% of the total consumption, was achieved.

The conclusions from the survey were that not only could the small steam boiler be shut down, thus saving 22,500 gal. of oil, but also the coal used in the Lancashire boiler could be reduced by 90 tons p.a., despite increased loading. The savings amounted to over £1,500 p.a.

Attention was then turned to the process side. The drying technique and the construction of the driers were investigated to see whether the time of processing could not be reduced. After modifications in the construction to provide a more uniform air flow, and adjustments to the operating technique, the time of the cycle was reduced from 56 to 36 hr. This new drying technique has opened the way for the use of certain chemical additives, with which the firm has been experimenting, and which will further reduce the cycle to 12 to 18 hr.

Another recent N.I.F.E.S. success was during the Suez crisis, when the organisation co-operated closely with the technical staff of Monsanto Chemicals Ltd., Ruabon. Like others, this factory was faced with a cut in oil supplies, but the savings achieved by improved combustion arrangements enabled the cut to be met comfortably, and gave the firm confidence that their production programme could be maintained.

New petrochemical project at Fawley

LATEST event in the story of the petrochemical and synthetic rubber projects connected with the Fawley refinery is that the Union Carbide Corporation has now announced its plans to erect a plant there for the manufacture of ethylene oxide derivatives. The plant's output will contribute to the expanding activities of Union Carbide Ltd., a British affiliate of the big American company.

Esso Petroleum Co. Ltd., which operates the Fawley refinery, is to supply the new plant with ethylene, which will be converted into a number of ethylene oxide derivatives. Operations are scheduled to begin in 1959, with a production capacity of 45 million lb. annually.

Some advanced chemical engineering will go into this installation and there will be a high degree of automation. Engineering studies have been completed and plant design is in the final stages, so that a start on construction can be expected shortly.

The Fawley plant is the second major petrochemical facility in the U.K. under construction by the Union Carbide organisation. The first, a 24-million-lb. p.a. polythene plant at Grangemouth, Scotland, is scheduled for completion very shortly.

Nitrate developments in Chile

IN spite of the development of synthetic production and the consequent decline in the use of natural nitrate since 1918 Chile's natural nitrate industry is still her second most important export industry after copper. The nitrate industry in Chile at present consists of 12 Shanks plants (the original process) and three bigger plants using the more modern mechanised Guggenheim process. These three plants belong to two large companies. The United States-owned Anglo Lautaro Nitrate Co. operates the two plants of Maria Elena and Pedro de Valdivia; the third plant at Victoria is operated by the Chilean Compania Salitrera Tarapaca y Antofagasta. These companies are big potential customers for a wide variety of the capital goods associated with mining—from the extraction and milling of the nitrate-bearing ore to the production of the final refined nitrate of soda, transportation to the coast and loading in ships. The mining is all open-cast and does not go underground. Anglo Lautaro export nitrate in granulated form; Tarapaca Antofagasta in crystallised form. The nitrate industry also produces iodine as well as smaller quantities of other chemicals associated with sodium nitrate. Anglo Lautaro is in the process of expanding such subsidiary production by means of the solar evaporation process.

These facts emerge from a recent survey which

reveals that the prospects for the Chilean nitrate industry are somewhat uncertain owing basically to the constantly expanding competition of synthetic nitrate. The difficulties have tended to become acute during the last 18 months. Production costs in Chile have risen and the price of nitrate, which was approximately $38 a ton at the end of 1955, has since fallen by some $4. The rise in freights is partly responsible for the reduced return in foreign exchange to Chile, since the price to the foreign buyer is determined by competing products and cannot be increased to cover increased freights. A large proportion of Chile's nitrate exports is sold in unconvertible currencies which under Chile's liberalised exchange system are at a discount here. On the other hand, Chile's export resources are limited and she cannot afford to neglect so important a product as nitrate in the face of difficulty. Over 500,000 tons (rather more than one-third of total production) are sold each year to the United States for dollars. The industry provides employment for over 19,000 working men. The policy of the nitrate companies supported by the Chilean Government is therefore to improve production methods by investing in more efficient plant and enable themselves to reduce production costs, use lower-grade ore and develop various sub-products.

Labels for chemical works gas casualities

A SERIES of labels for use in the case of gassing casualties in the chemical industry is making an important contribution to industrial safety. One of these labels sent along to the hospital with the casualty means that the hospital is given a correct history and diagnosis and is able to give the proper treatment straight away. Otherwise there is a danger that, because gassing cases are comparatively rare and because they come about through a variety of causes, it may take the hospital some time to discover what exactly should be done.

First introduced in 1952, the labels, which vary for different types of gases, have now been reviewed and some alterations made in the light of the latest knowledge. In addition to personal data regarding the patient and details of the exposure, each label contains three sections in which can be noted (1) first aid treatment, (2) the immediate treatment recommended to be applied either in the works surgery or immediately on arrival at the hospital, and (3) further treatment recommended. Apart from the more serious cases which are sent to hospital, the labels may also have a useful field of application where lightly-gassed casualties are sent to their homes. There is even a label which allows certain general principles to be followed in cases where details of the gas causing the patient's condition are not available.

The labels are produced by the Association of British Chemical Manufacturers in pads of 12 and have received the approval of the Ministry of Health and of various medical authorities. Information about them, along with specimen labels, is available in a booklet just published by the Association, price 5s.

Fuels and Fischer-Tropsch

ONE point that has been raised concerning the atomic energy programme in Britain is that when the generation of electricity from nuclear energy has reached a stage where it can replace other fuels for the production of heat and power for many purposes, and so reduce the overall demand for coal, it may then be practicable, provided that economic methods can be developed, to make oil synthetically from coal and its products to reduce the country's dependence on imported oil.

Research during recent years in Germany, the U.S., and Britain has indicated that the synthesis process can be further improved. But with proved techniques the major cost is in the production of the synthesis gas. Investigations into methods of gasification in Britain and in other countries and consideration of the results by the Fuel Research Station and the Chief Scientist's Division of the Ministry of Power, have indicated possible ways of greatly reducing the cost of making synthesis gas and of the process as a whole. On the basis of these recent developments and prospective improvements the Ministry have placed research and development contracts with industry and the Fuel Research Board have recommended some increase in the work on the Fischer-Tropsch process. Close collaboration is being maintained between the Station and the Ministry.

Progress of the British experiments on the Fischer-Tropsch synthesis was briefly commented on in these columns last month and the report ' Fuel Research 1956 ' just published (H.M.S.O. 4s. 6d.) points out that knowledge is still lacking as to the exact mechanism of the synthetis reaction, and factors which control the activity and other properties of catalysts are not well understood. Continued effort has therefore been devoted to studies of catalysts by gas adsorption and *x*-ray diffraction methods, to measurement of changes in the photoelectric work function of catalyst surfaces accompanying the adsorption of reactants, and to studies of reaction mechanism using radioactive tracer techniques. The possibility of modifying the behaviour of catalysts by exposure to ionising radiation is also being explored. In a more detailed examination of reaction products, increasing use is being made of chromatographic methods.

Space saving in soda ash storage

LARGE-SCALE consumers of soda ash solution can save up to 60% of valuable storage space by slurrying their soda ash with water rather than storing it the conventional way as the dry powder. This is because soda ash plus a limited amount of water forms a slurry of monohydrated crystals in a saturated solution. The density of the monohydrate slurry is much higher than that of dry soda ash.

This density relationship is the basis for an economical bulk handling system recently developed by Diamond Alkali Co. in the U.S. An ingenious sleeve-type check valve made of neoprene plays an

important rôle in the success of the system, according to technical information issued by E. I. Du Pont de Nemours & Co. which describes a typical installation operated by Lithium Corporation of America. Lithium Corporation of America is operating a typical installation at their Bessemer, N.C., plant. Dry soda ash is sucked from freight cars into each of two 74,000-gal. capacity tanks through a slurrifier — a specially designed, three-concentric-pipe unit that mixes the soda ash and water in the proper proportions and at the proper rate.

The dense monohydrate slurry quickly settles to the bottom of the tank in a layer up to about 15 ft. deep, leaving a clear supernatant layer of saturated (30%) soda ash solution at least 3 ft. deep. Solution is drawn off from the top layer to processing operations as required. To replenish the depleted solution layer and, incidentally, to keep the slurry layer fluid, water is introduced as required through 88 sparging nozzles arranged in a grid at the bottom of the tank. The nozzles are screwed into 1¼-in. feeder pipe, they point downward, and they are sheathed with tight neoprene sleeves. These elastic sleeves permit fresh water to percolate up through the monohydrate slurry, extracting a saturated soda ash solution, but prevents solids backflow from clogging the nozzle openings.

The tank contents must be held above 95.7°F., transition point for the monohydrate, or else the entire mass would solidify. Lithium Corporation hold their tanks between 105 and 120°F. with a thermostat, using 25 p.s.i. steam introduced through the sparging nozzles. This exposes the neoprene sleeve valves to steam at about 265°F.

An indication of the service given by these neoprene valves is that they have wanted practically no maintenance during over 2½ years' continuous operation of the soda ash storage system.

Cost-saving boiler for Stanlow

A BOILER of a type new to the United Kingdom was recently installed at Shell's Stanlow refinery at Ellesmere Port, Cheshire. The operation of the new unit will result in an estimated saving of the equivalent of 30,000 to 40,000 tons p.a. of heavy fuel.

Instead of conventional fuel, this boiler uses mainly gases from the catalytic cracking unit which formerly were discharged to atmosphere. Resulting from regeneration of the catalyst used in the catalytic cracking process, these gases, in addition to being at an already high temperature, are also combusted in a suitably designed burner to give more heat; the combined heat from both these sources is used to raise steam in the new boiler. Designed by Shell technologists, the boiler was constructed by John Thompson of Wolverhampton.

The gases are led from the top of the catalytic cracking unit, which is over 200 ft. high, by a duct 5 ft. in diameter and specially designed to withstand high temperatures and erosion resulting from the small catalyst particles in the gas stream. The tying-in of this new boiler has altered the well-known appearance of the catalytic cracking unit at Stanlow refinery. The gleaming new pipe that now connects the cat cracker to the steam boiler replaces the familiar tall single stack.

New natural-gas industries in France

'I HAVE seen oil refineries and chemical plants in many countries, but I have never seen anything so pretty as the works at Lacq. The sight of those low, white buildings and brightly coloured pipes and towers in the midst of the hilly, wooded countryside would make any normal child clap its hands in delight. Even the water tower, usually an eyesore, is a thing of beauty which the locals call *chateau d'eau*.'

This eulogistic commentary, which appeared in a recent contribution to the *Manchester Guardian* by Richard Fry, seems to suggest that chemical plants, suitably designed, and quite apart from their main function, might have potentialities hitherto unsuspected by their designers as the successors to the fairy castles of old. However, much more romantic to the engineer is the fact that the plant referred to, which lies between Pau and Bayonne in south-western France, owes its existence to some mighty deeds of derring-do on the part of those who overcame the ugly dragon Corrosion. This appeared as a result of the high sulphur content of the natural gas at Lacq, which is also reported to come up at six times the normal pressure and nearly three times as hot as any known natural gas in Europe or America, and to require elaborate control equipment. In view of these formidable problems, American consultants on the scene advised the French to leave the field alone and look elsewhere. But the chance of reducing France's dependence on imports for 40% of her energy needs was not to be abandoned without a great effort. The result was that a year or so ago one company of the Pompey group produced pipes of a steel that could withstand the combined attack of very high temperature, high pressure and sulphuric corrosion. The technical problem having been solved, it remains to be seen how long a service will be given by the steel pipes and how much this will affect production costs.

The first unit of the desulphurising plant was completed earlier this year; it treats 1 million cu.m./day of natural gas, the purified gas being piped to various communities as far away as Bordeaux and Toulouse. Besides modest quantities of propane, butane and motor spirit, there is an annual supply of 55,000 metric tons of very pure sulphur.

The next unit will handle another 4 million cu.m./day of crude gas and is to be completed late in 1958. Further extensions are planned which should bring very considerable increases in the volume of gas treated. With these extensions will come aluminium and chemical projects to bring about a transformation of this agricultural area. This is in line with the development of chemical and allied industries in south-west France generally, as described by D. C. Freshwater in CHEMICAL & PROCESS ENGINEERING, 1953, **34** (12), 388-391.

ZIRCONIUM AND TANTALUM

By G. L. Miller, Ph.D., B.Sc., A.R.I.C., M.I.Chem.E., M.Inst.M.M.

Great interest has been shown in zirconium and tantalum, two metals which, although more expensive than conventional metals of construction, have considerable potentialities for the chemical engineer as corrosion-resistant materials. Dr. Miller sums up the properties and possibilities of these materials for us.

TANTALUM, first produced over 50 years ago, has been employed for special applications in the chemical industry for many years and, despite its cost and the development of competitive materials, its use has expanded. Zirconium, a relative newcomer to the chemical industry, has made its name in the nuclear industry, where the combination of low thermal neutron capture cross-section and excellent corrosion resistance resulted in its employment as a canning material in the packaged power type of reactor, such as the water-cooled pressurised unit used so successfully in the U.S. submarine *Nautilus*.

The rapid development of zirconium technology is due entirely to the interest taken by nuclear engineers and this is reflected in the expansion from pilot-plant production of 60 lb./week in 1947 to a current production of 7 million lb. p.a. Except for a token production in the U.K. and France, this production is entirely in the U.S., with Japan supplying a few hundred tons a year to the U.S. Atomic Energy Commission.

It has been known for a long time that the corrosion-resistant properties of zirconium were good and it is difficult to explain why so little advance has been made in using it in the chemical industry. It is probable that the following points explain, at least partially, the failure:

(1) For several years all research was aimed at the employment of zirconium in reactors.
(2) Some of the early metal was contaminated, particularly with carbon, resulting in misleading data being published.
(3) High cost.
(4) Reluctance of users to change from a material such as tantalum, which was perfectly satisfactory.

In favour of zirconium is the ample supply of cheap ore, while tantalum ores are scarce and expensive.

Production and fabrication

Both metals are very reactive; their production requires considerable processing and involves the use of expensive equipment. Zirconium can be consolidated by arc melting to yield large ingots weighing about 1 ton, while tantalum, with its much higher melting point, is still in the main consolidated by powder metallurgical methods. Tantalum and zirconium are both fairly easily fabricated. Zirconium permits more hot working than tantalum, although they are both rapidly oxidised at elevated temperatures. Welding is satisfactory with both metals provided precautions are taken to avoid oxidation.

[*Courtesy: Murex Ltd.*
A 6-ft. tantalum bayonet heater for use in sulphuric acid concentrators, as supplied to Shell Chemical Co. Ltd. at Stanlow.

Corrosion resistance

Both metals are expensive, but zirconium will eventually become much cheaper than tantalum due to expanding production; in addition, its density difference will contribute a substantial saving in cost of equipment.

The zirconium industry has increased enormously due to the Atomic Energy Commission requirements and, although the tantalum industry is growing, its expansion is not hitched to a project which entails almost unlimited expenditure.

As far as corrosion resistance is concerned, both of the metals are excellent in most acids, but tantalum is attacked by alkalis, while zirconium is not. The following table gives some indication of their corrosion-resistant properties:

Medium	*Zirconium*	*Tantalum*
Acetic acid	Boiling conc. excellent	Boiling conc. excellent
Aqua regia	Poor	Excellent
Phosphoric acid	Excellent-fair	Excellent
Sodium hydroxide (soln. and fused)	Excellent	Poor
Sulphuric acid	Excellent dilute Poor concentrated	Excellent
Ferric chloride	Poor	Excellent
Hydrochloric acid*	Excellent cold Good boiling	Excellent
Nitric acid	Excellent	Excellent
Potassium hydroxide	Excellent	Poor

* Corrosion data for zirconium in hydrochloric acid varies a great deal, but the latest information from the Carborundum Metals Co. shows penetration figures less than 0.0002 in. p.a. for all concentrations up to the boiling point with 20% acid. Up to 25% acid at 325°F. resistance is excellent, at 400°F. 15% concentration results in a corrosion rate of less than 0.005 in. p.a.

Tantalum in chemical plant

Tantalum has been employed chiefly as a material for heat-transfer equipment, such as heating and cooling coils, bayonet heaters and condensers. Hydrochloric acid absorption plants with the heat-transfer units made of tantalum are used all over the world. Tantalum equipment also finds a use where contamination in the material being processed must be avoided, such, for example, as some drugs and pharmaceutical products. Despite the cost of tantalum, it is economical to use this metal for special applications, especially as the tantalum can be employed in a very thin form from 0.013 to 0.02 in. thick. In most applications the life of the tantalum is very long and once installed the equipment may be expected to last indefinitely. Instances have been quoted where tantalum equipment has been used continuously for 20 years without corrosion and without maintenance.

Outlook for zirconium

Zirconium is still trying to find its feet as a corrosion-resistant material. Tests done at the U.S. Bureau of Mines, Albany, showed that zirconium was suitable as a tank lining and for ejectors, fan blades, valves, spray nozzles and pump parts. There is no doubt that all these parts can be constructed from zirconium; the problem is to find suitable applications and this depends to a considerable extent on the cost. To compete with tantalum, zirconium must prove that it is as good, *i.e.* that it can be installed and left for several years—only time can show whether zirconium is as suitable. Zirconium prices in the U.S. are changing rapidly and $3.5/lb. of sponge metal is now mentioned; this is very much cheaper than tantalum, but until zirconium has proven itself to be as good as tantalum there will be great reluctance to change. To compete with the more common corrosion-resistant materials which are used for less exacting purposes means competing with stainless steel. At present this is impossible and even if the price falls, as predicted in the U.S., there is little likelihood that zirconium will be as cheap as stainless steel and therefore it must be proven that it is so much better that it is more economical to use it. Corrosion data sheets are not sufficient; actual practical applications are the only certain way to prove material for corrosion-resistant applications.

Conclusion

Tantalum production is expanding and the producers do not appear to be concerned about the increasing production and simultaneous falling price of zirconium. The zirconium producers in the U.S. are predicting a great future for zirconium in the chemical industry and every argument in favour of this metal will be published.

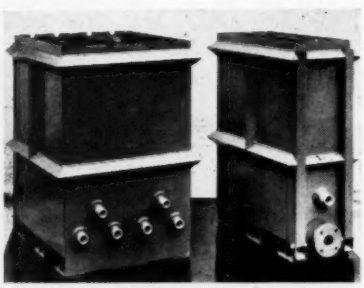
It would appear that tantalum will not be easily and quickly supplanted as a material for specially severe corrosive conditions, nor stainless steel as a relative cheap material usable for less severe conditions.

Expanded Metal Reinforcement for PVC Sheet

Although one of the strongest of the thermoplastic materials, *Cobex*, when used for the construction of chemical plant, often suffered from the fact that temperatures above 60°C. were difficult to handle and that large unsupported areas of sheet often required much stiffening. A new development of *Cobex* sheet goes far towards satisfying the demand for a material having its excellent all-round resistance combined with higher mechanical strength and temperature potential.

The new material is a laminate of expanded metal and *Cobex* and is available in sheets up to 8 ft. by 4 ft. and thicknesses from $\frac{1}{8}$ in. It has a number of advantages over the non-reinforced material, including greater rigidity and a resistance to impact load superior even to that of *Cobex*/*Velbex* laminates.

As such it is eminently suitable for the construction of vessels where in many cases before its introduction a steel shell would have been necessary. Its greater rigidity makes possible its use with much higher temperatures than hitherto.



These tanks, used in the production of a chemical used for preventing scale in evaporators, illustrate the use of 'Cobex' with expanded metal reinforcement. They were produced by Tanks & Linings Ltd. for G. & J. Weir Ltd.

In considering the strength of the material as shown by deflection, a sheet will have greater resistance to bending *across* the expanded metal than along the diamond-shaped section. But even loaded the weak way it is still considerably stiffer than the unreinforced thermoplastic.

In the manipulation of the sheeting a number of new factors must be taken into consideration if the fullest use is to be made of its potentialities. It goes without saying of course, that a thinner reinforced sheet can be employed for a given duty and would provide equivalent mechanical strength as well as superior temperature resistance. Certainly much advantage is gained by being able to use the new sheet where a flush surface free from protecting stiffeners is necessary or desirable.

The thinner sheets having a light gauge metal can be bent to sharp radii without difficulty, but thicker sheets with a heavier metal require a press for such bends. One advantage the metal-reinforced material has over unreinforced *Cobex* is that the free edges of curved sheets do not tend to curl and, of course, two or more bends may be made in successive operations without fear of the sheet reverting to flat during re-heating.

When cutting, the conventional methods may be applied and guillotining is permissible. In this latter case, however, considerable care is advisable to prevent shatter of the *Cobex* along an edge.

In so far as welding is concerned, no great difference in technique is required, although the presence of the metal calls for careful work. This is especially so with thinner sheets where the proportion of *Cobex* to metal is lowest.

Both clear and opaque sheets are available and it might be considered a psychological advantage to be able to see the metal reinforcement. Also, of course, where the direction of the metal run is important in the design of the fabrication it would be a distinct handicap to have to examine the edges of an opaque sheet. On the other hand, welds usually do not show to the best advantage in a clear material.

For the moment, certainly, expanded metal reinforced material should be complementary to *Cobex*. Used in combination the two types of sheet will make it possible to overcome some hitherto insoluble problems.

We have to thank Mr. Beech of Tanks & Linings Ltd., and BX Plastics Ltd., for the foregoing notes.

Aluminium *v.* Corrosion by Water

By E. W. Jackson, A.M.C.T., A.M.I.Chem.E.

This article surveys data on the action of water on aluminium under various conditions and raises some points concerning the design of aluminium plant and equipment for such conditions.

BECAUSE of its excellent corrosion resistance to many substances, as well as its good mechanical and other physical properties, aluminium is extensively used as a constructional material in chemical engineering. The metal is available wrought and cast and in various degrees of purity; the forms in which it is marketed are covered by several British Standards.[1] The following table gives some idea of the purity in which sheet and strip may be obtained:

B.S. 1470 *Designation*	*Aluminium*, %	
S1	99.99	super purity
S1 A	99.8	
S1 B	99.5	
S1 C	99	commercial purity

The advantages of aluminium as a constructional material compared with other materials of similar corrosion resistance are: low cost, low density, high strength/weight ratio, high thermal conductivity, low emissivity and low cross-section capture for neutrons. It is non-sparking and has a low catalytic activity; the corrosion products are colourless, and the metal is reported to be non-toxic. Some of the limitations of aluminium are its low strength, low melting point, softness and loss of strength with increase in purity.

Raw water is sometimes conveyed in aluminium pipes, the metal being very useful for this purpose where the corrosion products from alternative constructional materials would impart undesirable colours to the product being manufactured. Water also frequently comes into contact with the metal for cooling purposes in heat exchangers. Aluminium is sometimes used for the manufacture of distilled water when the metal is used for stills, condensers, pipes and storage tanks.

The choice of materials of construction for nuclear reactors is limited by nuclear physics considerations, and the low cross-section capture of aluminium for neutrons has led to the extensive use of the metal in the atomic energy field, particularly as a metal which comes into contact with water. The mechanical weakness of aluminium at high temperatures has led to the development of other alloys for the canning of fuel elements for gas-cooled thermal reactors,[2, 3] but for water-cooled reactors special aluminium alloys are being investigated for use at high temperature and pressure.

Action of waters on aluminium at temperatures up to 100°C.

The action of water on aluminium is a very complicated subject on which many papers have been published. The element is extremely reactive chemically, and its resistance to corrosion depends upon the formation of protective films on the surface of the metal. The natural air-formed film has a thickness of approximately 10^{-6} cm.[4] and it probably consists of amorphous Al_2O_3. The film formed in water is usually *Bayerite* $Al(OH)_3$ at normal temperatures and *Böhmite* AlO(OH) at 70 to 100°C.[5]

Bryan[6] has studied the action of boiling distilled water on aluminium of varying purity; he found that the metal and its alloys react initially with boiling water with the evolution of hydrogen, and the formation of a highly resistant protective film on the surface of the metal. Impurities and alloying elements in the aluminium influence the rate at which the film forms and the amount of corrosion which takes place before it is complete. Evidence was also found that a certain minimum quantity of free silicon is necessary in aluminium to arrest its corrosion by boiling water.

Aziz and Godard[7] discovered that the addition of more than 0.05% iron or 0.3% silicon to super-purity aluminium increased the probability that pitting would occur in Kingston, Ontario, tap water at room temperature, but such additions did not affect the behaviour of metal containing 99.75% aluminium because of the high initial iron and silicon content of the lower-purity metal.

The corrosion of aluminium in supply waters has been investigated by Porter and Hadden.[8] Most of the tap waters tested caused severe pitting of aluminium and its alloys; changes in the composition of the water had a greater effect on the corrosion than had changes in the alloys, but the order of attack was the same in all the waters tested. Corrosive attack was most severe in the harder waters, the typical form of attack being the development of deep pits covered by mounds of aluminium hydroxide (nodular pitting) as seen in Figs. 1 and 2. Under substantially stagnant conditions a mound of insoluble hydroxide forms beneath which acid liquid is trapped and pitting occurs. Regular removal of corrosion products discourages pitting attack. The conditions for nodular pitting are the presence of calcium bicarbonate, chloride, copper salts and dissolved oxygen.

It was found by Wright and Godard[9] that the water from Lake Ontario caused pitting of aluminium, but when specimens of aluminium were immersed directly in the lake, pitting of the metal was not observed. They considered that water velocity may have prevented the initiation of pitting of the samples immersed in the lake, and this was confirmed by experiment. Using Kingston tap water, which is drawn from Lake Ontario, these authors have shown that the probability of pitting taking place diminished with increase in the rate of water flow over aluminium. Water velocities from 1 to 10 ft./min. were used for the experiments, and at velocities of 8 ft./min. and above pitting of the aluminium did not take place. The composition of Kingston tap water is shown in the following table:[10]

*p*H	8	
Residue on evaporation	161	p.p.m.
Total hardness	127	,,
Bicarbonate as HCO_3	113	,,
Sulphates as SO_4	22	,,
Chlorides as Cl	16	,,
Calcium	37	,,
Magnesium	8	,,
Silica	4	,,
Iron	0.05	,,
Copper	0.015	,,

Action of waters on aluminium at high temperatures

The development of nuclear energy has led to intensive research in recent years into the action of water on aluminium at high temperatures.

In 1929 Guillet and Ballay[11] reported that pure aluminium disintegrated in superheated steam at 300 to 350°C., but impure aluminium was found to be more resistant to corrosion at these temperatures than the pure metal. The determination of aqueous corrosion rates for commercial-purity aluminium have shown it to be suitably corrosion resistant for the cladding of fuel elements for water-cooled nuclear reactors up to temperatures of 200°C., but above this temperature the metal develops blisters and suffers penetrating attack.[12] An alloy has been produced containing 1% nickel which appears to be safe against penetrating attack up to 350°C.,[12] and the results of static corrosion tests carried out in distilled water are encouraging.

The protective film

The above examples show some of the lines on which research into the corrosion of aluminium by water has been pursued. Radioactive tracer technique has been used to study the pitting corrosion of aluminium,[13] and papers have been published which cover the general principles of the corrosion of aluminium.[14, 15]

The corrosion of aluminium is a surface film problem and the resistance of the metal to corrosion depends upon the protective film remaining unbroken, the resistance of the film to attack and the resistance of the film to penetration by ions. Some of the factors which will influence corrosion are:

(1) Temperature of the water

The behaviour of water towards aluminium at high temperatures is totally different to what it is at normal temperatures. Whilst much experimental work has been published on the action of aluminium at high temperatures, insufficient information is available at present on the large-scale use of aluminium alloys at temperatures above 100°C. to enable a definite statement to be made. Work on commercial-purity aluminium in nearly pure water at temperatures up to 200°C. has shown that initially corrosion is rapid and is followed by a constant lower rate of corrosion. The experimental constant lower rates of corrosion are recorded as approximately 0.02 to approximately 2.5 mg./sq.dm./day (mdd.) at 200°C.[16] In the case of one supply water, pitting was reduced by increasing the temperature, and at 50°C. was almost absent.[17] In certain waters increase in temperature may lead to the formation of scale on the heating surface which will protect the aluminium from corrosive attack.

(2) Composition of the aluminium

(*a*) *Temperatures up to* 100°C. Super-purity aluminium is not used commercially for the handling of water. In general the purer the aluminium the more resistant it is to corrosion by water; metal of 99.8% purity is only used where very low rates of corrosion are essential. Usually metal of 99.5% purity is satisfactory, and often metal of 90% purity can be used. Copper is an undesirable constituent, and it should be kept to a minimum. In the case of sea water, aluminium alloys containing manganese are more resistant than aluminium itself and they are extensively used for marine work.

(*b*) *Temperatures above* 200°C. Unalloyed aluminium is quite unsuitable for use at temperatures above 200°C., and a new class of alloys containing iron, nickel and silicon or titanium is being developed for use in water-cooled nuclear reactors at high temperatures.[18]

(3) Nature of the impurities in the water

There is reason to suspect that absolutely pure water is very corrosive towards aluminium[19] and that traces of silica or other impurities inhibit the action of nearly pure water on aluminium. The metal is generally regarded as a suitable constructional material for the manufacture of distilled water, and figures have been published which show that an aluminium system does not materially contribute impurities to distilled water.[20]

The protective water-formed film on aluminium is soluble in acids and in alkalis and the *p*H at which it has minimum solubility is between 6 and 7 at temperatures up to 100°C. Ideally, the *p*H of water to be handled in aluminium at normal temperatures should be maintained between 6 and 7,

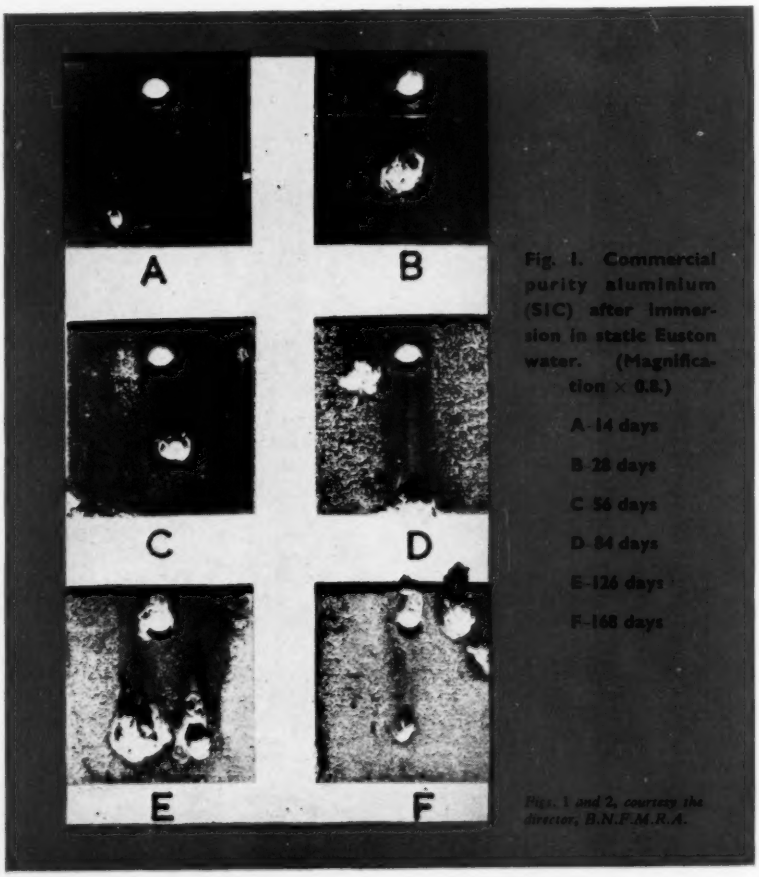


Fig. 1. Commercial purity aluminium (SIC) after immersion in static Euston water. (Magnification × 0.8.)

A–14 days
B–28 days
C–56 days
D–84 days
E–126 days
F–168 days

Figs. 1 and 2, courtesy the director, B.N.F.M.R.A.

but in certain circumstances it may be possible to go outside these limits. For example, acid waters having a *p*H of about 4, in the absence of heavy metals and chloride ions, have been found to have little effect on aluminium and its alloys.[21] The *p*H of water increases at high temperatures, placing it outside the range of minimum solubility of the protective water-formed film. It has been found that the *p*H of nearly pure water must be adjusted to 3 at room temperature in order that it may have minimum attack on the protective film at 300°C.[16]

The protective film on aluminium can be penetrated by certain ions; the small ions chloride, bromide and iodide show high penetration[22] and are undesirable in waters which are in contact with the metal.

Traces of heavy metals in water can enormously increase its corrosion towards aluminium. Providing calcium bicarbonate chloride and dissolved oxygen are present in water in fair quantity concentrations of the order of 0.02 p.p.m. of copper can cause severe nodular pitting.[23] Silver, tin, lead, cobalt and nickel are harmful in extremely low concentrations. Graphite is also an undesirable impurity as it can initiate pitting.

The experience at the Aluminium Laboratories, Kingston, Ontario, is that fairly hard, mildly alkaline water such as the Great Lakes system tends to pit aluminium while soft mildly acid waters do not.[9]

(4) Velocity of the water

Some metals such as aluminium and its alloys may be protected or less corroded at high rates of movement because the more rapid renewal of dissolved oxygen at the metal surface leads to better maintenance of the protective film.[24] It should not be forgotten that in a corrosive environment high rates of movement may increase corrosion; there is evidence that in water at *p*H 7 and above, and at 95°C. at *p*H 4 to 4.5, the corrosion rate of aluminium in nearly pure water is strongly dependent on flow rate.[25]

(5) Design of the system

In plant design recirculation of water is best avoided when using aluminium equipment as practically all recirculated water becomes corrosive to aluminium.[26] Recirculated water may dissolve heavy metals from other parts of the system, such as pumps and pipes, and build up dangerous concentrations. There is also the danger that undesirable impurities may be taken up from the air. In

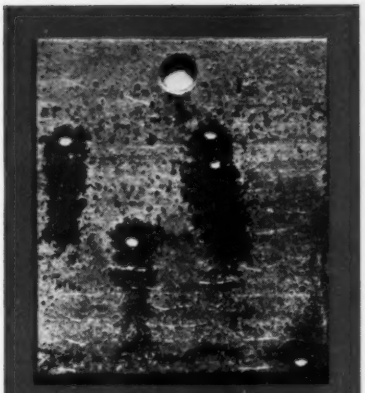


Fig. 2. Commercial purity aluminium wrought sheet (S1C) after 24 weeks' immersion in Birmingham water (copper supply pipes). (Magnification × 1.)

circumstances where recirculation of water must be accepted some form of treatment or purification should be included in the design.

During the fabrication of aluminium great care must be taken to avoid the introduction of traces of heavy metals into the surface of aluminium, otherwise the resistance to corrosion will suffer. Non-conducting inclusions can also influence the resistance to corrosion by interrupting the protective oxide film.[27] Other points to be observed in the design of aluminium equipment for chemical plant are discussed by Dummett.[28]

Corrosion tests

Apart from certain well-defined cases, the results of research so far published do not permit the action of any industrial water on aluminium to be predicted. Before designing any aluminium plant involving contact with water, corrosion tests should be carried out under the conditions of use. The aluminium should be of the actual composition and metallurgical condition which will be employed for the fabrication of equipment.

Where corrosion is known to take place, it may be reduced by cathodic protection with zinc. In other cases, an inhibitor such as sodium silicate or sodium chromate may be useful. In the case of sodium chromate, it is important to see that there is sufficient inhibitor in solution at all times, otherwise corrosion may be accelerated. If an inhibitor is being considered it should be tried out during the corrosion tests under the conditions of use to see if it is effective.

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Resins. Eight summary sheets from British Resin Products Ltd., Devonshire House, Piccadilly, London, W.1, give data for various applications of *Cellobond* adhesive and binder resins.

Cathodic Protection for the Chemical Industry

By C. L. Wilson, B.Sc.
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The design of systems for the cathodic protection of various types of plant and equipment used in the chemical industry are briefly summarised.

CATHODIC protection is the science of building electrolytic cells in such a way that the metal surface being protected against corrosion becomes the cathode of the cell. Theoretically, any metal that is corroding due to contact with an electrolyte may be protected by this means. In the chemical industry the practical problems are those of anode material, as in the majority of applications there is very little space in which to introduce anodes.

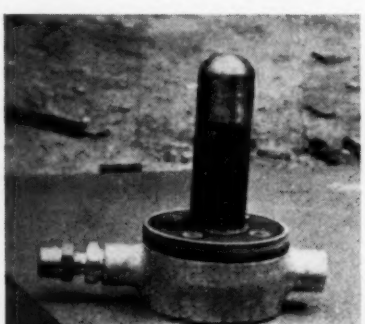
The main applications that have been attempted to date have been in the cooling systems of plant, particularly where salt water has been used. Table 1 shows a list of standard applications with a rough guide to the type of anode materials that have been found suitable in practice. The bias is towards the impressed-current system (this uses external d.c. power for the driving voltage of the cell) rather than the sacrificial-anode system. The former gives external indication of efficient operation and produces a cheaper installation over a period, due to the longer life of the anodes. The costs of anode replacements depend on the cost of the material, labour costs in installation, and often loss of production due to shut down. Labour costs and loss of production are generally far higher than material costs.

Determining cathodic protection requirements

The design of systems for these types of applications is often based purely on past experience. However, it is possible to generalise to a certain extent. The first step is an investigation as to whether other anti-corrosion methods, including special painting and coating and special materials, may be cheaper. Having ascertained that cathodic protection is a possible solution, the second step is to determine the area of metal to be protected. The area and the state and nature of the metal will determine the current requirements for full protection. For example, bare steel will require 10 to 15 ma./sq.ft.; well-coated steel something less than $\frac{1}{4}$ ma./sq.ft.; aluminium 1 to 2 ma./sq.ft.; anodised aluminium a mere microamp/sq.ft. Having determined the current required the next step is to investigate the anode material and type of system most suitable. A detailed examination of the standard applications will assist here.

Condensers and dephlegmators. These can be divided into two distinct types: coolant through the tubes and coolant round the tubes. Coolant flowing round the tubes will only leave space for long, narrow anodes laid longitudinally between sets of tubes. This will eliminate most sacrificial anodes, as they require bulk to give long life. For the impressed-current anode it is clear that graphite and silicon iron are impracticable as they are so brittle. Suitable anode materials are thus steel rods, platinum, CX3 lead alloy and aluminium. The choice will often be decided by the physical dimensions, current requirements and nature of the electrolyte.

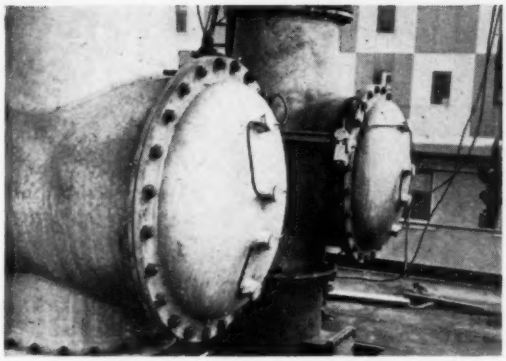
Coolant through the tubes will produce corrosion of end boxes, face plates and the first 6 to 9 in. of the tubes. The only space available will be in the boxes, and anodes are normally mounted on the box covers. Sacrificial anodes and bulky impressed-current anodes are very suitable where there is plenty of room and they will not interfere with the flow. Where room is limited, impressed-current systems with platinum or CX3 lead alloy anodes have proved to be by far the best. The positioning of anodes will be governed by the number of passes (normally one anode per pass), but it will be found useful to have symmetrical designs to achieve evenly distributed corrosion of the anodes.



CX3 alloy anode unit for dephlegmator. Overall length approx. 6 in.

Storage tanks. These are among the easiest of applications. Small tanks will be best protected by any sacrificial anode (magnesium if they are bare) and large tanks by impressed-current means. Anodes are normally suspended in the electrolyte in an array that gives equal distribution of protective current. The array design has to be considered carefully, as the danger spots are any corners, and the current must be ' thrown ' into them.

Autoclaves. Problems must be treated on their individual merits. The choice of anode material will depend to a great extent on temperature, pressure and the nature of the electrolyte. It has been found that metallic impressed-current anodes



CX3 alloy anodes mounted in two dephlegmator end boxes.

(which take up little space) are the most widely used. Impressed-current schemes are definitely preferred, as control of protection level can be achieved during operation.

Pumps (internal). It is very rarely that cathodic protection is suitable for such problems. The standard pump is normally a gigantic corrosion cell that is best protected by an alteration of materials or the use of insulating bushes. Where cathodic protection has been applied, sacrificial systems have generally been used as inspection periods for pumps are short and so the anode life can also be short.

Pumps (outside casings). Submerged pumps are again comparatively easy problems, as long as the casing is not of a very complicated shape, and most of them are not. Any of the anode materials may be used and the final choice is generally determined by local conditions. The most commonly used materials reported have been scrap steel and magnesium.

Valves (gate type). Here it is impossible to generalise. There is a vast combination of possibilities of valve materials, design and electrolyte handled. Designs of cathodic protection schemes in this type of work are often the result of individual ideas and 'design flair,' and designs are very rarely repeated.

Internal walls of pipes. Small-diameter pipes can be protected, but the cost is generally prohibitive because the influence of any introduced anode is between 4 and 5 diameters of the pipe. This means that for a 6-in. pipe an anode must be introduced at every 2 ft. 6 in. along its length. On the other hand, large-diameter pipes may be protected without being previously lined. Cases have been reported of unlined pipelines being protected by cathodic protection at a lower initial cost than that of internally lining the pipe. Choice of anode materials is rather limited due to the difficulty of supporting the anodes inside the pipe. Impressed-current systems are to be preferred, but too often the pipelines are located where no power is readily available.

Other design considerations

Once the type of anode for the application has been determined the application becomes a problem of Ohm's law. Information on the resistance of the anodes and their current output in the particular electrolyte will determine how many will be required. Sacrificial anodes have known driving voltages to various metals to assist in this determination. For impressed-current systems the required voltage is calculated from resistance and current values and the power unit and feeder cables specified accordingly.

The major problem then left outstanding is the method of anode mounting. This in itself is a complete study, as it involves knowledge of mechanical and chemical properties of a wide range of materials. An anode working at fairly high current densities in sea water will be constantly surrounded by an electrolyte containing oxygen and nascent chlorine. The most suitable mounting materials to date seem to be *Tufnol*, wood and mild steel with complete neoprene shrouding.

It is very certain that cathodic protection will eventually be recognised as part of standard chemical engineering design practice. It is understandable that designers reared in an atmosphere of costly anti-corrosion metals and plastics should tend to overlook fundamental methods like cathodic protection, but the trend over the past few years seems to be towards these methods. Experience of cathodic protection engineers has been that quite often the best economics result from a combination of mild steel and cathodic protection.

Table I. Anode Materials and Applications

Application	*Sacrificial*			*Impressed current*					
	Mg	*Zn*	*Al*	*Scrap steel*	*Graphite*	*Silicon iron*	*Platinum*	*CX3 lead alloy*	*Aluminium*
Condensers and dephlegmators	S	S	S[1]	U	SH[4]	S	S[5]	SL[1]	S[4]
Storage tanks	S	S	S[1]	S[4]	SH	S	S[3]	SL[1]	S
Autoclaves	S	S[2]	S[1]	U	U	S	SH	SL[1]	S
Pumps (internal)	SH[4]L	S[2,4]	S[1]	U	U	S	S	S[1]	U
Pumps (outside casing)	S	S	S[1]	S[4]	SH	S	S[3]	SL[1]	S
Valves—Gate type	SH.L	S	S[1]	U	U	S	S[3]	S[1]	S
Internal walls of pipes	SH	U	U	U	S[3]	S	S	SL[1]	S

[1]Low-resistivity electrolytes only
[2]Subject to temperature limitations
[3]Not very economical
[4]Large units
[5]Small units

S = Suitable
U = Unsuitable
SH = Best for high-resistivity electrolytes
SL = Best for low-resistivity electrolytes

Metallic Materials of Construction

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The properties, applications and method of fabrication of the commoner metals of construction for chemical and other industrial plant are briefly summarised.

IN the manufacture of industrial and chemical plant the conditions and requirements of service are very wide indeed. The chemical industry in particular makes very exacting demands on the design and fabrication of plant for its use. The range of materials in general use is already extensive, but developments are constantly being made on new materials to meet more severe service conditions and to improve the performance of existing materials. Of particular significance is the increasing use of the epoxy resins for coatings on mild steel, giving a remarkable degree of chemical inertness. Also titanium can now be considered as a valuable chemical engineering material with exceptional corrosion resistance, particularly to sea water and solutions of most metal chlorides.

Two of the most important factors affecting the design of such plant which demand careful consideration are corrosion and fabrication by welding. Corrosion resistance is a basic requirement involving the parent material, weld metal and the heat-affected zones of the parent material. It must always be remembered that corrosion rates will vary according to the concentration, temperature, pressure and degree of aeration of the corrosive media. The surface finish may also be important, since irregularities such as porosity or crevices may give rise to local intensification of corrosion or sources of contamination of the product.

Fabrication by welding has revolutionised the design of industrial and chemical plant. It is the most efficient method for the joining of materials with greater reliability and provides flexibility in design. In many cases it is the only method of fabrication. Therefore the weldability factor becomes a prime consideration in the problem of material selection. Rapid progress has taken place in the industry by the development of new processes and techniques. Worthy of special mention are the argon arc, shielded inert gas metal arc, submerged arc and *Fusarc*/CO_2 processes.

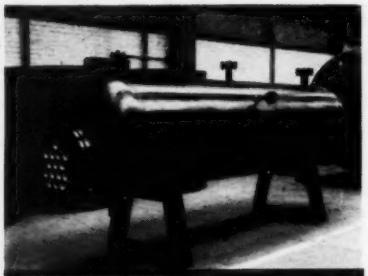


Fig. 1. Mild-steel 'Downthrow' vaporiser complete with two tube bundles.

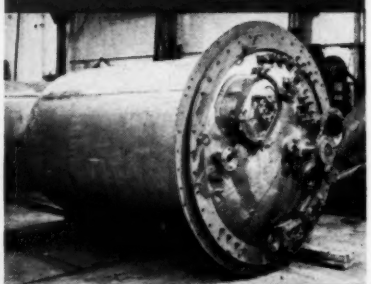


Fig. 2. Mild-steel jacketed mixing vessel, fabricated in 18/8 molybdenum bearing stainless steel.

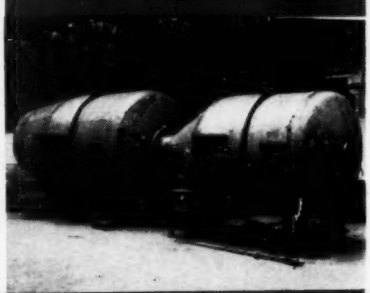


Fig. 3. Vaporiser and condenser fabricated in 18/8 titanium-stabilised stainless steel.

The chief materials of construction and their application may be reviewed briefly under the following heads:

Mild steel

By far the largest proportion of plant is constructed in mild steel, which possesses excellent workability and weldability by all processes. Mild-steel vessels are widely used for the storage and transport of petroleum products and derivatives, *e.g.* fuel oils, petroleum spirits, kerosene, bitumen, tar etc. The limited corrosion resistance of the metal can be overcome by the application of metallic and non-metallic linings chosen according to the specific service conditions. Metals, such as zinc, tin, aluminium and nickel, can be applied by hot dipping, electroplating and spraying. As liners and protective coatings plastics have already proved successful within limitations of temperature. Phenol-formaldehyde coating compositions have been used for many years. Rubber-lined tanks are much used for resistance to acids, in particular hydrochloric acid. All internal surfaces must be carefully prepared and welds must be ground flush and be completely sound to receive the coating material.

In cases where the more expensive materials, such as stainless steel, *Monel* and nickel, are required to meet the corrosive conditions, but where the thickness of material necessary for strength would make the plant costly, it is often possible to use the clad steels, an applied lining, or weld overlays. In the fabrication of such vessels careful procedure is necessary to preserve the clad layer. Also a thorough knowledge of metallurgical principles is necessary to ensure fully satisfactory welds without the development of dangerous dilution zones or loss of corrosion resistance at the clad face.

Although the manual metal arc process accounts for a large number of welded joints in mild steel, automatic welding processes are being increasingly used to give better quality welds with greater economy. A typical mild-steel vessel is shown in Fig. 1, where the shell welds were welded automatically by the submerged arc process.

Stainless steel

This series of steels based on chromium and nickel plays a vital part in plant for many industries. Although there are many compositions, the great majority of industrial applications can

be met by a small number of steels. These steels combine good corrosion and scaling resistance, strength and toughness at high and low temperatures with workability and weldability and are capable of taking a high surface finish. Selection of the most suitable grade of stainless steel for a specific purpose must receive careful and competent consideration and data available from the suppliers provide a useful guide. In many cases it is sound practice to carry out trials under the actual service conditions.

The weldability of stainless steels has received very detailed consideration. Problems such as intercrystalline corrosion, 'knife line' attack, hot cracking, ferrite content and sigma embrittlement have been thoroughly investigated and their mode of occurrence established. Metallurgical control of hot working and stress relief heat treatment is essential. With technical control and experience in the fabrication of these steels these pitfalls are eliminated and a high quality of product obtained.

All the welding processes can be used for stainless steel with the metal arc and argon arc processes predominating. The inert gas metal arc process has been used successfully on the thicker sections, deep groove and fillet welds. A welding procedure must be drafted which has taken into consideration all the factors concerned, such as efficient design, process to be used, composition of weld metal and distortion.

The fabrication of any stainless-steel plant must be done under clean conditions. Material must be carefully handled to avoid excessive surface damage, particles must not become embedded in the surface and iron-free grinding and polishing materials used. Figs. 2 and 3 show typical examples of chemical process plant and Fig. 4 illustrates the quality of finish obtained in production of jacketed stainless-steel pans.

Fig. 4. Jacketed pans in 18/8 titanium-stabilised stainless steel dull-polished finish.

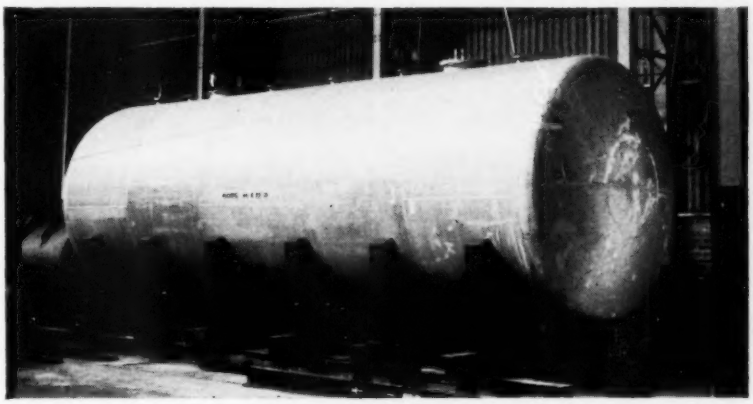


Fig. 5. Storage tank for concentrated nitric acid, in 99.8% pure aluminium.

Aluminium and aluminium alloys

Until recent years aluminium and aluminium alloys were not widely used as materials suitable for chemical plant, despite the fact that they combine the properties of lightness, reasonable strength and inherently good corrosion resistance. The main reason for this lack of use can be attributed to welding difficulties. The development of the argon arc process and the inert gas metal arc process has resulted in increased demand for fabricated plant to contain concentrated nitric acid, fatty acids, certain organic acids, resins, foodstuffs and other substances. The low specific gravity of aluminium and aluminium alloys is attractive to the designer of road and rail transport tanks.

The argon arc process is primarily used for the thinner sections, short runs and components involving frequent changes in section and shape. The inert gas metal arc process cannot be used for thicknesses less than $\frac{1}{8}$ in., but is effective for thicker materials and continuous welds, in particular fillet welds. Good-quality welds can be obtained in pure aluminium and the non-heat-treatable aluminium - magnesium alloys and progress is being made in the welding of the heat-treatable alloys. Fig. 5 shows a storage tank 30 ft. by 9 ft. by $\frac{1}{2}$ in. thick fabricated by the argon arc and inert gas metal arc processes in 99.8% pure aluminium. Fig. 6 shows a triple hopper unit for the bulk transport of flour or cement fabricated in aluminium-magnesium alloy N5/6, using the two types of argon shielded welding processes.

Nickel and nickel alloys

In many cases where stainless steels, aluminium or lined mild-steel materials cannot meet the required service conditions, nickel and the high-nickel alloys are used. *Monel* is effective for resistance to non-oxidising acids, salt solutions and halogen compounds. Nickel finds particular use in cases where complete resistance to caustic alkalis is required and also for resistance to a wide range of corrosive media. More recently developed alloys include *Corronel B*, which gives superior resistance to non-oxidising solutions of hydrochloric and sulphuric acids at relatively high concentrations and temperatures, and *Ni-o-nel*, which is resistant to dilute hydrochloric acid, salt solutions and moderate concentrations of sulphuric acid at intermediate temperatures.

The metal arc process is primarily used for the welding of these materials, but with the development of special

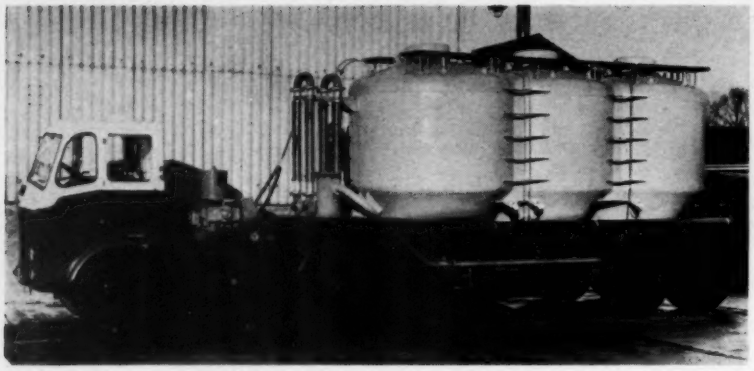


Fig. 6. Triple hopper unit for bulk transport of flour or cement, fabricated in N5/6 aluminium-magnesium alloy.

Fig. 7. 3,200-gal. single-compartment transport tank for phenol, fabricated in pure nickel with nickel steam heating coil. Insulated with glass fibre covered with aluminium sheets.

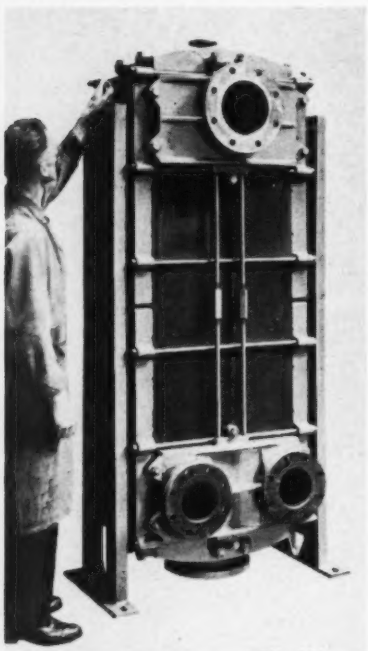
deoxidised filler wires the argon arc process will give satisfactory sound welds. Absolutely clean conditions must be maintained throughout the fabrication of nickel and nickel alloys, since any sulphur-bearing grease, paint or other foreign matter present will cause severe intercrystalline cracking on heating. Recently the largest road transport tank in pure nickel was fabricated in our works and is shown in Fig. 7.

Conclusion

In completion of this brief summary it is necessary to emphasise that the quality of the end-product is directly related to the control of all operations from the inception of any contract. Careful selection of material, efficient design with special emphasis on weldability and technique, planned procedure, effective supervision and first-class inspection will provide a standard of quality and reliability which must be obtained for plant required for service in the chemical, atomic energy, petroleum, food and other industries.

Graphite Heat Exchangers

Graphite is a material of construction which, despite the advent of many newer materials, continues to offer a number of unique advantages in many anti-corrosive applications. Its usefulness is well illustrated by the success of graphite heat exchangers which are robust units designed on the now well-known cubic principle.



One of the new 150-sq. ft. heat exchangers.

The makers of these heat exchangers, Powell Duffryn Carbon Products Ltd., report that by employing new resin impregnants, nearly all organic materials can now be handled safely, whether heating, cooling, boiling or condensing; mixtures of organics and inorganics can also be handled. This has resulted in the use of these units as condensers in the pharmaceutical industry, and also for general applications in the petrochemical industry where such mixtures are encountered. In the latter case, the units have been specially modified to handle pressures up to 100 p.s.i.

In the synthetic detergent industry there are many of these exchangers working as sulphonation coolers under extremely corrosive conditions while in the food industry, exchangers are employed on duties which are not particularly corrosive, but where metal contamination or discolouration must be avoided.

The basis of every Powell Duffryn heat exchanger is the so-called sub-assembly consisting of a graphite block held in compression by two clamping plates. By varying the choice of header, the same sub-assembly may be used for a wide range of flows.

At the present time, sub-assemblies are available ranging from 1.5 sq. ft. to 250 sq. ft. of heat transfer area. There are some 28 distinct sub-assemblies; for convenience these can be divided into five groups.

Group 1—covers units based on 9 in. and 15 in. tube lengths of $\frac{3}{8}$ in. diameter.

Group 2—the same as Group 1, but with narrow slots substituted for circular holes to double the capacity of the block when handling gases or when operating as a condenser.

Group 3—units based on 9 in. and 15 in. tube lengths but with $\frac{3}{4}$ in. diameter holes, designed specifically for the pickling industry and other applications where heavy scaling is anticipated. The short tube, coupled with the larger hole size facilitates easier cleaning.

Group 4—new range of heat exchangers based on 6 ft. tube lengths with either $\frac{3}{4}$ in. diameter holes or $\frac{3}{8}$ in. $\times$ $\frac{3}{4}$ in. slots.

Group 5—miscellaneous units. Among these units is the viscose cooler, specially designed for the synthetic fibre industry, operating with fluids of 90 to 100 poises viscosity. This exchanger has tubes approximately 7 in. long and $\frac{1}{4}$ in. diameter.

New Weapons Join the War on Corrosion

This month, as part of 'National Anti-Corrosion Week,' a full-scale Corrosion Exhibition—the first of its kind to be held in Britain—will reveal the progress of anti-corrosive materials of construction, coatings, techniques and services. Here is a preview of some of the exhibits to be seen there. Organised by our associate journal Corrosion Technology, *the Exhibition is being held at the Royal Horticultural Society's Old Hall, London, S.W.*1, *on October* 15, 16 *and* 17. *The headings given below are only arbitrary and do not cover the whole of this comprehensive Exhibition, which includes surface coatings, zinc-rich paints, plastic coatings, metal treatment, hot-dip galvanising, metals, anti-corrosive plastic components, flooring, water treatment, anti-corrosive fluids, wrapping tapes, cathodic protection, corrosion research, technical publications, and flame cleaning.*

Metals

New alloys based on the copper-manganese-aluminium system are claimed to possess a high degree of resistance to corrosion, high strength and fatigue resistance, coupled with excellent castability, hot working properties and welding characteristics. J. Stone & Co. are exhibiting three pieces of test equipment which have been used in the development of these alloys. The first of these is an apparatus used in determining the cavitation erosion resistance of various alloys, while the second is used to obtain information regarding the corrosion resistance of a large number of materials in a variety of corrosive media. The test liquid is caused to move past the specimens by blowing through it a stream of air or nitrogen. Speed of flow, degree of aeration and temperature of the corrodant are thus all controllable. The third exhibit is a standard Wöhler fatigue machine used for the determination of corrosion-fatigue resistance, in which the critical section of the specimen is continually wetted by a spray of test liquid.

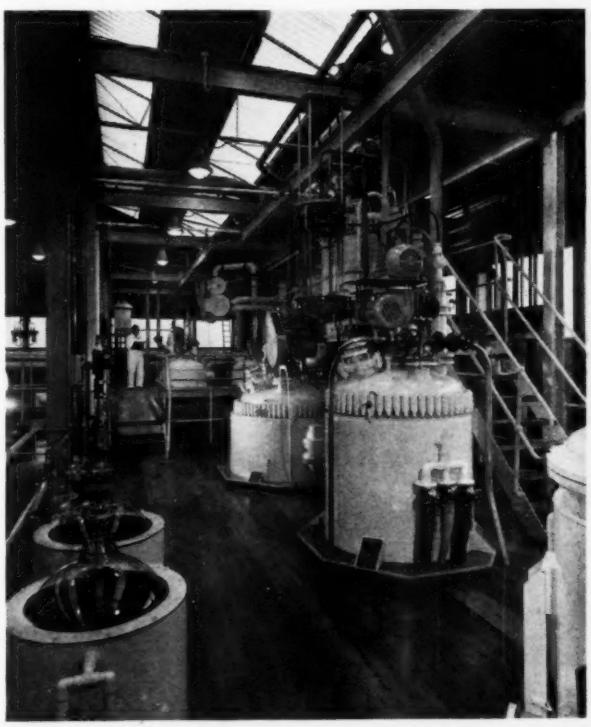
Indications of the work of I.C.I. Metals Division on the development of 'canning' materials in aluminium and magnesium alloys for nuclear reactors will be given on the Division's stand and reference will also be made to intensive work on other metals such as zirconium and niobium. The corrosion-resistant properties of titanium will be stressed in that section of the display which refers to the chemical and oil industries.

Plastic materials of construction

The corrosion-resistant material *Keeglas*, based on the use of glass fibres with epoxy and polyester resins, will be shown by Kestner Evaporator & Engineering Co. Ltd. A working unit will be exhibited, comprising a *Keeglas* tank with a transparent PVC pump and *Keeglas* stirrer fitted. This unit will pump liquid through a corrosion-resistant pipework system from and to the tank.

Another company exhibiting plastics items will be St. Helens Cable & Rubber Co. Ltd., who are engaged in the application of plastics, such as rigid PVC, polythene and glass-resin laminates, to chemical engineering, and examples of pipework and other fabrications in these materials will be exhibited.

Apart from providing information on the anti-corrosion uses of *Epikote* resins, Shell Chemical Co. Ltd. will show their developments in the field of non-corrosive constructional materials such as Ziegler low-pressure high-density polythene which is



A view of the cortisone plant of Boots Pure Drug Co. Ltd., Nottingham, in which the ironwork, girders, etc., have been decorated and protected by 'Metavin' coatings supplied by Croda Ltd.

claimed to be outstanding in a number of ways, but in the context of corrosion control its lower permeability to gases and vapours in greater resistance than that of earlier polythenes to solvents, especially hydrocarbons, is particularly noteworthy. Shell's polyvinyl chloride, *Carina*, is another constructional plastic with useful applications in anti-corrosion.

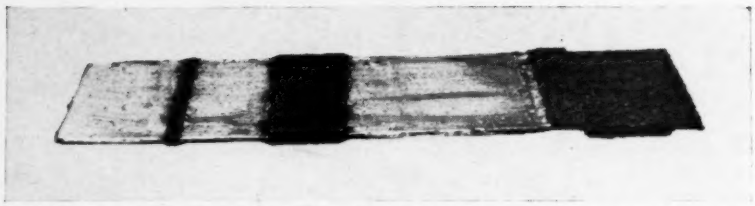
The newest addition to the range of rigid plastic pipe to be shown by Chemidus Plastics Ltd. is manufactured from a recently developed rigid PVC composition, specially modified to give particularly high shock resistance. The company's range of corrosion-resistant piping has been extended to include piping up to 15 in. bore. The smaller diameters in Chemidus tubing are primarily intended for chemical plant and pipework, but above 6 in. diameter this tubing finds its main application for fume extraction work.

A display of chemical plant fabricated in the main from rigid vinyl will be featured by BX Plastics Ltd., the manufacturers of *Cobex* rigid vinyl sheet.

Pipe protection

For the first time, examples of *Guardion* anti-corrosion self-adhesive tape will be displayed by F. A. Hughes & Co. Ltd. This tape has a polyvinyl chloride base spread on one side with a key-coated pressure-sensitive adhesive. It has a high tensile strength, moulds easily, has excellent electrical properties, is highly resistant to water, oil, acids, alkalis, bacteria, fungi etc. Since it is available in a number of colours it is ideal for indicating pipe runs in addition to its protective values.

Particular attention will be drawn to the protection of pipelines in pitch and bitumen enamels reinforced with glass fibre tissue by Neuchatel Anti-Corrosion Ltd. They will also illustrate the supply and installation of *Asphalate* for the simultaneous protection and insulation of *hot* pipelines conveying oil, water, or steam. *Asphalate* is a powdered form of natural asphalt blended with asbestos and is simply packed round the pipe in the trench or duct carrying it. A sintered non-corrodible coating forms round the pipe while the remainder of the *Asphalate* packing constitutes an efficient waterproof form of insulation, it is stated.



This photograph illustrates a mild steel plate which has been treated in bands with D.M.U. Zinc Rich Primer. The unprotected areas will be seen to have corroded greatly but little or no creep has occurred under the painted surfaces. The amount of corrosion is easily visible, as the products of corrosion occupy approximately nine times the volume of the steel from which they were formed.

On the stand of Winn & Coales Ltd. will be a display of the *Denso* range of anti-corrosion products, which are supplied in the form of tapes, cords, mastics and lacquers.

John Gosheron & Co. Ltd. will be exhibiting their range of plastic anti-corrosion pipe protection and electrical tapes, some of which are the result of very recent development in the plastics field, together with pipe-wrapping machines for use in conjunction with them. Foremost in the PVC tape range is a new tape, *Vylap*, in which the adhesive qualities are inherent in the material itself, no separate adhesive spread being required. Pipe cleaning solvents and priming fluids, with anti-corrosion additives will be similarly featured in the display, while wrapping of tapes by machine will be demonstrated with the use of the Gosheron *Viper* pipe-wrapping machine. The *Viper* incorporates several novel features, automatically ensuring the correct tension and overlap on the tape, and it can be used to provide double wrapping protection for special applications.

The Smith & Nephew stand will be devoted to *Lassovic* PWG self-adhesive tape—a PVC base material spread on one side with a tie-coated, pressure sensitive adhesive which is stable under the most exacting field and climatic conditions. *Lassovic* PWG is suitable for wrapping and protecting metal structures and pipelines above or below ground.

Anti-corrosion treatment

A series of metals, treated by the sodium-hydride process for the removal of foundry sand, descaling and derusting, will be shown by D. & H. Metal Treatments Ltd. of Staines. The major advantage of sodium hydride is that the process attacks the scale, or sand, and not the metal. It ensures entire clearance of sand from any casting. The metals shown will include nickel alloys, titanium, cast iron, etc.

Shell-Mex will be showing two of their rust preventives—fluids 256 and 260. They consist of protective materials and additives rendered fluid by solvents.

The Plus Gas Co. Ltd. have introduced a new product which is a tannating process for the preparation of rusted metal surfaces prior to painting. This material is known as Formula 'E' external metal treatment, and is of particular advantage for the treatment of metal surfaces, as the tannate/gamma-ferric oxide complex formed by reactions of the tannins with the oxides on the metal surfaces creates an insoluble corrosion-resisting film which stands up to the weather for a number of days, even in exposed positions. Under cover the coating will remain intact for several months, and inside buildings, under normally heated and ventilated conditions, the film will last indefinitely. The tannin film is claimed to afford an excellent bond for other protective coatings. It does not chip or flake, being an integral part of the metal surface. It prevents the formation of rust under paint, so considerably prolonging its life. Further features are that it is non-acid, non-toxic and non-injurious.

A feature of the stand of the Hot-Dip Galvanizers Association will be galvanised nuts and bolts side by side with a 20-ft. structural section to illustrate the versatility of the process with regard to the size of object that can be handled. The cooling coil, with its complex arrangements of fins, shows how the molten zinc flows over every part of the most complicated surface and forms a protective coating against the influences which cause rust.

The Jasons Model 3B de-rusting pistol will be shown by John Trelawney Ltd. It is an air-operated

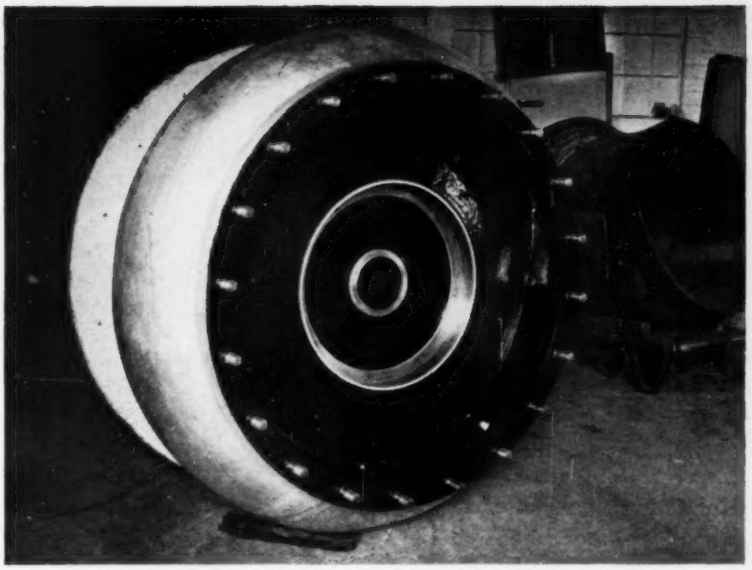
hand tool designed mainly for de-rusting or descaling ironwork prior to painting. It can also be used to roughen surfaces for metallising; clean weld seams or castings; strip paint or bitumen etc.

Rubber and allied coatings

The properties of a chlorinated rubber paint will be illustrated by applying a film of this paint in a clear form (unpigmented) to a Bank of England £5 note. On to this note will be dripping concentrated sulphuric acid. The exhibitors, Detel Ltd., will also illustrate the latest developments in heat-resisting aluminium paints by heating mild steel treated panels to approximately 1,000°F. on to which water will be dripped, demonstrating the tenacity of such a coating.

Another chlorinated rubber paint, *Evodyne*, will be seen on the stand of Evode Ltd. This heavy-bodied, chemical-resistant paint gives protection to iron, steel and woods subjected to attack by acids, alkalis, corrosive gases and salt water. It can be applied to alkaline surfaces—concrete, brickwork, plaster, asbestos, cement etc. It is dust dry within 30 min. and may be overpainted within 12 to 24 hr.

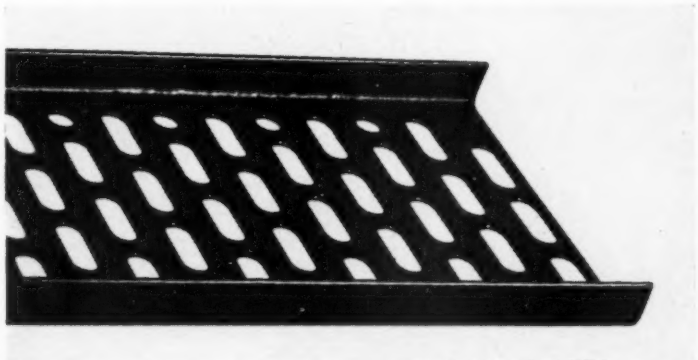
A firm specialising in the protection of metal surfaces subject to corrosion, erosion and electrolytic action by influences of seawater, circulated river water containing solid matter in suspension and other contaminated cooling waters, Protective Rubber Coatings (Bristol) Ltd., will be exhibiting large size photographs of jobs which they have executed. These will feature *Limpetite*, a neoprene-based product stated to be very suitable for the protection of metal employed in the chemical industry.



Ex-service 24 in. pump bowl protected internally with Synco neoprene-based coating.

Specialists in engineered neoprene-based coatings, Anglo-American Synco Corp. Ltd., will be exhibiting a 24-in. cast-iron pump bowl which has been rehabilitated by the application of *Synco* neoprene-based coating after a period in service on salt water which had caused severe corrosion. Photographs showing the condition of the bowl prior to coating will also be on show. Also on the stand will be a section of coated heat exchanger tube sheet, complete with tube-ends protected by the *Serand* method against erosion and impingement attack; neoprene-coated wedge gate valves, together with uncoated ex-service valves illustrating the extent of damage which can be caused by corrosion when no form of protection is used, and examples of *Synco* neoprene-based coating applied to a range of both ferrous and non-ferrous materials.

A series of coatings based on neoprene which they say is equally suitable for protection against 50% sulphuric acid or 50% caustic soda has been developed by E. & F. Richardson Ltd. The firm state that a chemical company concerned with the corrosion and erosion of centrifugal pump impellers and cases handling hot terephthallic acid slurry have found that *Semprene-Adcora* coatings have gone a long way towards solving their problem. Ammonium sulphate centrifuges in one steel works and one gas works have also been successfully protected.



Some steel cable tray which has been HD polythene coated to give a corrosion resistant and insulated surface. This is widely used on tankers and in refineries and chemical plants generally (Durable Plastics Ltd.).

Metallic coatings

Samples of chromised steel and nickel (or nickel alloy) parts treated by the *Arkrom* process will be in evidence on the stand of Metallic Surfaces Research Laboratories Ltd., while the comparative resistance of treated and untreated steel to oxidation will be shown on a panel. The degree of oxidation for each set of samples will illustrate at the same time the measure of protection obtained by *Arkrom* treatment and the effect of temperature on the extent of thermal oxidation of both treated and untreated steel.

Recent developments in tin and tin alloy coatings will be presented on the Tin Research Institute's stand, including tin-nickel electroplate, an

alloy remarkable for its inertness to attack by the majority of corrosive media. One notable advantage is that repeated condensation upon the tin-nickel surface does not affect it.

Plastic coatings

Many articles coated in PTFE, PTFCE, polythene, nylon and PVC will be displayed on the stand of Durable Plastics Ltd. In addition, they will show items of cathodic corrosion equipment, which have been insulated with PVC and sprayed nylon coatings, for use under highly abrasive conditions.

James Lithgow (U.K.) Ltd. will show a range of *Calvinac* plastic coatings and linings claimed to offer protection against a wide variety of corrosive conditions aggravated by physical factors of abrasion, temperature and vacuum. As well as straightforward corrosion problems these resins are used to prevent metallic contamination of products in the food and pharmaceutical industries. They are used to prevent adherence of sticky substances during handling in the milling and soap industries.

The Croda Ltd. stand will feature three examples from their range of anti-corrosive coatings. *Crocell*, a strippable thermoplastic coating applied by dipping the required article in a molten solution; *Metavin*, and *Rhino Hide*, described as an extremely tough strippable plastic coating applied cold by spray gun.

For controlling boiler corrosion due to dissolved oxygen, a dissolved oxygen recorder will be shown by Wallace & Tiernan Ltd. The equipment provides accurate determinations of small quantities of oxygen and gives a record free from drift, independent of chemical interference and with a rapid response to oxygen changes.

A range of *Cabtyrit* compounds, based on natural and synthetic rubbers, will be featured by St. Helens Cable & Rubber Co. Ltd. Exhibits include samples of natural rubber, heat-resisting natural rubber, abrasion-resisting natural rubber, ebonite (hard rubber), ebonite (low temperature vulcanising), flexible ebonite, polychloroprene (neoprene), PVC and butyl.

Miscellaneous coatings

Phenolic chemical-resistant undercoat and finishing paints, useful for the finishing of structures subject to corrosive conditions, particularly acid fumes, are to be found in the *Drynamel* range. The makers will also be showing their *Drygalv* zinc-rich paint, stated to give cathodic protection to iron and steel in the same manner as hot-dip galvanising. Drynamels Ltd. are the exhibitors.

The stand of Wailes Dove Bitumastic Ltd. will be of special interest to the chemical industry as *Bitumastic* coatings provide a high degree of resistance against chemical fumes, vapours etc. The principal feature of the stand will be a model showing the complicated operations of cleaning, priming, coating and wrapping a pipeline by line travelling machine.

A new range of sealants will be exhibited by British Paints Ltd. along with apparatus which illustrates what happens on the interior surface of a boiler tube while steam is being generated, and the particular advantages to be gained from their *ApeXioR* process for such surfaces—even up to 1,000°F. Another exhibit shows the behaviour of a number of coatings whilst being used in connection with cathodic protection.

Other exhibits

The Aero Research Ltd. display will feature applications of their *Araldite* range of epoxy resins, which are used in the anti-corrosion field for protective paints, glass fibre laminates, cements and stoppers, as well as for adhesive and potting compounds. The use of woven glass cloth impregnated with *Araldite* as a protective coating or raw material has been particularly successful. The resulting laminate has a high strength/weight ratio, is resistant to damage and is non-corrodible.

The conductivity meters to be shown on the stand of Elga Products Ltd. will be of particular interest to corrosion technologists. They will also be showing an entirely self-contained deioniser that produces distilled water at tap speed. It is a dual purpose model, and conductivity water (4 million ohms/cm.) may be drawn at flow rates of 5 to 7 gal./hr. A recent modification enables the user to adapt the *Elgastat Major* to the recirculating principle. Instead of running the effluent to waste after use, it is collected and circulated back through the column. In this way, the very considerable quantities of washing water required for many processes can be obtained with a minimum of capital cost.

CHEMICAL & PROCESS ENGINEERING, Corrosion Technology *and other journals, technical books and books of reference published by the Leonard Hill Technical Group will be on display on Stand No.* 39, *which is the Leonard Hill stand.*

WHITE KNIGHT CHECKMATES CORROSION

'O what can ail thee, knight-at-arms, Alone and palely loitering?'

Unlike the knight of Keats' well-known lines, there was nothing ailing about the stalwart figure who greeted guests at the door at a recent Leonard Hill Technical Group reception in London. But pale his armour may well have appeared, for he was the White Knight, the one who (in 'Through the Looking Glass') sang to Alice about his plan 'to save the Menai Bridge from rust by boiling it in wine.' He was, therefore, well fitted to take part in heralding 'National Anti-Corrosion Week,' which includes the Exhibition described in the foregoing pages and the Corrosion Convention mentioned in our 'Topics of the Month.'

The 'White Knight,' pictured here, is in real life Mr. Ernest Hill,

CHEMICAL & PROCESS ENGINEERING'S manager, and he was, therefore, only performing his normal rôle of crusading in the interests of chemical engineering.

Chinese Advances in the SYNTHESIS OF LIQUID FUELS

By Chang Ta-Yu, Leo Nan-Tsuen and Chang Chun-Hao
(*Institute of Petroleum, Academia Sinica*)

Research on the synthesis of liquid fuels from carbon monoxide and hydrogen via *a fluidised process has been in progress at the Chinese Institute of Petroleum, a branch of Academia Sinica, for over three years. Pilot-plant data using a nitrided fused-iron catalyst have been obtained, indicating that good operability can be realised at a fair selectivity level. Further work to improve selectivity of the catalyst is in progress. The cobalt catalyst has also been investigated in this Institute. The surface complex of silica and cobalt was found to be closely related to the quality of the catalyst.*

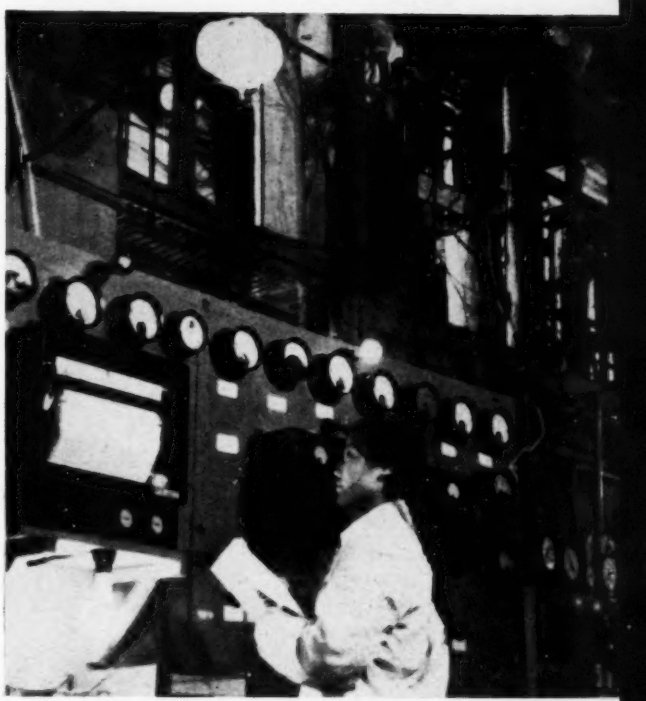


Fig. 1. Taking readings from an experimental liquid fuel synthesis unit, referred to in the article.

THE feasibility of applying the fluidised catalyst technique to the synthesis of liquid fuels from carbon monoxide and hydrogen has been a subject of much controversy in recent years. This process is remarkable for its ability to remove heat rapidly from the reactor, and by maintaining a uniform catalyst bed temperature, a high space time yield can be realised. On the other hand, several serious drawbacks have become evident ever since the process was developed.[1] Thus, defluidisation frequently occurs as a result of accumulation of heavy products on the surfaces of catalysts when the process is operated at low temperatures, while a high reaction temperature would induce rapid carbon deposition with consequent deterioration of the catalyst and "blow-over." The poor stability of ordinary fused or sintered iron catalyst makes the task of choosing satisfactory operating conditions a very difficult one.

Anderson and his co-workers[2] claim several distinct merits for the use of iron nitrides as catalysts in gas synthesis, the most important of which are their resistance to carbon deposition and their greater mechanical strength. Also the low molecular weight product from such catalysts is an advantage to be utilised in fluidised reactors at relatively low temperatures. Anderson recommended their use in the fluidised synthesis on these grounds.

Process research on synthetic liquid fuels has been in progress at the Chinese Institute of Petroleum, a branch of the Academia Sinica, since 1950. At first, the work dealt chiefly with precipitated iron catalysts.[22, 23] During the past three years, however, efforts have been directed toward the development of a fluidised process using nitrided catalysts. This work has included (1) catalysts testing in fixed-bed units of 7-30 ml. capacity, (2) bench-scale and (3) pilot-plant studies (capacity: 2 and 30 litres catalyst respectively) as well as analyses of products. With the aim of improving selectivity of the catalyst the effects of process variables, catalyst composition and mode of preparation have been studied. A brief summary of pilot-plant data thus obtained is presented below. Finally some results from the study on the cobalt catalyst are also reported.

Table 1. Operating Conditions, Conversions and Yields obtained in Pilot-plant and Small Fluid Unit Runs

Reactor:	*30-litre unit*								*2-litre unit*
Experiment No.	500[15]				700[16]				037
Type of catalyst	nitrided				nitrided				nitrided and alkalised
Hours on stream	120	530	780	1,120	90	420	910	1,530	600-928
Temperature °C.	260	260	260	260	260	275	260	260	260
Pressure atm.	15	15	15	15	15	15	15	15	25
Space velocity*	850	1,060	1,200	1,000	800	800	800	1,800	863
Recycle ratio	4	4	4	4	4	6	6	2.5	4
Contraction %	62.1	58.7	57.3	57.7	56.9	59.7	62.2	60.5	64.8
CO conversion %	92.2	92.2	90.1	89.2	87.7	88.1	90.7	92.4	94.0
H_2/CO feed ratio	1.36	1.21	1.24	1.28	1.28	1.30	1.26	1.27	1.34
H_2/CO consumption ratio	1.23	1.08	1.13	1.16	1.15	1.21	1.24	1.16	1.21
Product distribution Wt. %:									
CH_4	11.6	17.4	17.7	17.4	15.5	16.2	16.9	—	7.8
C_2 sat. and unsat.	12.1	13.0	13.6	13.4	9.7	10.7	12.0	—	8.8
C_3 unsat.	7.0	7.7	7.5	6.0	17.2	17.9	20.5	—	11.5
C_3	7.8	7.2	7.5	9.0					
C_4 unsat.	7.2	6.7	8.4	7.5	9.9	11.0	11.2	—	8.4
C_4	4.9	4.4	3.0	3.5					
C_5–C_{11}	35.1	31.0	32.3	33.5	34.9	31.4	29.5	—	35.2
C_{12+}	5.6	3.7	3.1	3.4	7.7	5.8	4.8	—	11.3
Oxygenates	8.7	8.9	6.9	6.3	7.4	6.4	4.3	—	15.9
Loss	—	—	—	—	0.7	0.6	0.8	—	1.1

*Litres synthesis gas at N.T.P. per litre of catalyst per hour.

Study of iron catalysts

A nitrided fused-iron catalyst was tested at normal pressure, and it did not show any drop in activity in a three-week interval. However, the selectivity was poor and the space velocity of synthesised gas could hardly be raised above 200 N.T.P. per l. of catalyst per hour which was required in order to obtain a high-feed gas conversion. Tests at 7 to 20 atm. gave constant CO conversions higher than 90% at space velocities above 1,000 for more than two months with product distributed over essentially stable range.[3]

The effect of particle size on catalyst performance became very marked at high throughputs. In contrast to the constant activity of 80 to 200 mesh samples at high space velocities, the 5 to 6 mesh granules showed sharp decline in activity with time.

In order to suppress excessive CO_2 formation during synthesis, the effect of process variables was studied rather extensively.[4, 5] It was found that the reaction pressure and recycle ratio were the most significant factors, while temperature and space velocity played less important rôles. The following relation was found to exist between the partial pressures of the components in exit gases:

$$\frac{P_{CO_2}\ P_{H_2}}{P_{CO}^{n}\ P_{H_2O}} = C \quad . \quad . \quad (1)$$

where n and C are constants under a given set of process conditions. With a H_2/CO feed ratio around 1.25, the loss in yield of hydrocarbons can be limited to within 8 g. cu.m. at N.T.P. of both gases if the pressure P (in atm.) and recycle ratio R are chosen to conform to the following expression:

$$P^{0.74}(R + 0.5) = 34 \quad . \quad . \quad (2)$$

It can be shown that equation (2) immediately follows equation (1), when suitable numerical values are substituted for the parameters.

The effect of catalyst composition on selectivity was investigated. As the N/Fe mole ratio was lowered, a decrease of 17 g. of $CH_4 + C_2H_6$ yield per normal cu.m. of feed gases (CO/H_2) was observed in the 1½-in. fluid unit. The corresponding gain in C_{3+} yield was, however, obtained only with difficulty in operation.[6] Different ways of addition of alkali were compared and impregnation with a solution of potassium carbonate appeared to be the most promising.[7] A yield of methane of 10 g./normal cu.m. of $CO + H_2$ in fixed-bed unit and 15g./normal cu.m. of $CO + H_2$ in the small fluid reactor was found. A comparison of the activity of the alkalised catalyst and the normally nitrided ones may be found in Table 1. It was noted that although for different catalysts a shift of product distribution always accompanied the curtailment of methane formation, the two were not necessarily related by any unique function. From the data obtained in the small fluid unit, it was also concluded that the relative amounts of C_{3-4}, C_{5-11} and C_{12+} fractions did not conform to the distribution rule given by Manes[8]:

$$W_{r+}/W_{3+} = a^{r-3}\left[\frac{r - a(r-1)}{3 - 2a}\right] \quad (3)$$

where constant chain growth probability is assumed. In equation (3), r = number of carbon atoms per molecule of the product:

W_{r+} = Weight of C_{r+} fraction

a = chain growth probability.

The extent of deviation from the *constant a* rule appears to depend on the type of catalyst employed. Recently, successful operation has been attained at considerably higher selectivities and so the generally held opinion that selectivity and operability are incompatible seems now open to question.[21]

The effect of pressure on reduction of catalysts was also investigated.[9] Medium pressure was preferred in reduction with H_2 for two reasons:

Firstly, the time for complete reduction at 10 atm. was shortened to one-tenth of its value at atmospheric pressure. Moreover, the purity of H_2 was less significant when reduction was carried out at medium pressures. Presence of CO and CO_2 up to 3% did not prove to be harmful to the synthesis and moisture content corresponding to the saturation value at 30°C. was found tolerable. This is in striking contrast with previous work.[21]

Catalysts were tested for their resistance to oxidation by a CO_2 treatment: carbon dioxide was passed over the catalyst under synthesis conditions for 12 hr. and then the synthesis was resumed to see if any decline in activity occurred. This presented a quick check in addition to the routine test of durability.

Analysis and stoichiometry

The investigation of product distribution and catalyst selectivity called for a new scheme of analysis.[9a] A gas-solid chromatographic method similar to that proposed by Janak,[10] using CO_2 as elluent and active carbon adsorbent, was used together with the conventional Orsat method for the analysis of feed and exit gases. The composition of twelve components—*i.e.*, CO_2, C_{3+} olefins, C_2H_4, O_2, CO, H_2, N_2, CH_4, C_2H_6, C_3H_8, C_4H_{10} and C_{5+} paraffins—was obtained in about an hour, with an average deviation between parallel runs less than 0.2% (the deviation could be reduced further to less than 0.05% with a modified procedure). The results also agreed well with those obtained by low-temperature fractionations using a micro column. Substitution of thermally treated silica gel for active carbon as the adsorbent in the chromatographic column gave the analyses of a mixture of CH_4, C_2H_6, C_2H_4, C_3H_6, C_3H_8, n-C_4H_8 and n-C_4H_{10} immediately. Typical results are shown in Table 2.

By this simple and expedient method methane, ethane, ethylene could be determined and C_3^+ yields calculated therefrom.[11, 11a]

The oxygenated compounds in both the aqueous and oil layers of the products were analysed for their functional groups by chemical methods. The aqueous phase was also analysed for its total organic carbon. Such a scheme has proved to be more straightforward than that of Bashkirov[12] in stoichiometric computations.

In the calculation of theoretical yields, hydrogen, oxygen and 'contraction' balances were made along with the usual carbon balance. Volume contractions computed by formulæ similar to those derived by Rapoport[13] were employed in preference to measured contractions, as the latter values were subject to greater experimental errors. A number of interesting stoichiometric relationships have been derived.[14]

Two of them are:

$$c = \tfrac{1}{3}(2 - u + m + e + \triangle) \quad . \quad (4)$$

$$c = \tfrac{1}{4}\left(3 + \triangle - \frac{K}{N_{CO}\, x}\right) \quad . \quad (5)$$

where c, m and e = moles of CO_2, CH_4 and C_2H_6 formed respectively, per mole of CO reacted.

u = H_2/CO consumption ratio

K = contraction, volume %

x = CO conversion, %

N_{CO} = mole fraction of CO in feed gas

and $\triangle$ = a minor correction term, which involves the degree of unsaturation of C_{3+} hydrocarbons and carbonyl and carboxyl formation and which can usually be neglected.

In this laboratory, the calculated C_{3+} yield and the actual yield generally agree to within $\pm$ 5%.

Pilot-plant synthesis studies

Erected in 1953, the pilot plant had a daily fresh gas throughput of 500 cu.m. (see Fig. 2). A 'wet' recycle flow system was employed in the plant, the recycle stream being saturated at room temperature with C_{3+} hydrocarbons. The reactor is a 150 mm. × 4 m. seamless steel pipe, which was topped with a disengaging section of 300 mm. × 2 m. and surrounded by a cooling jacket. Heat of reaction was removed by circulation of a naphthalene-diphenyl ether mixture in the jacket. Along the reactor there were a total of 26 equally-spaced side taps, which serve as thermocouple wells, pressure taps as well as the sampling stations for catalyst and reacting gas.

Eight runs have already been performed in the pilot plant. Table 1 summarises the pertinent data ob-

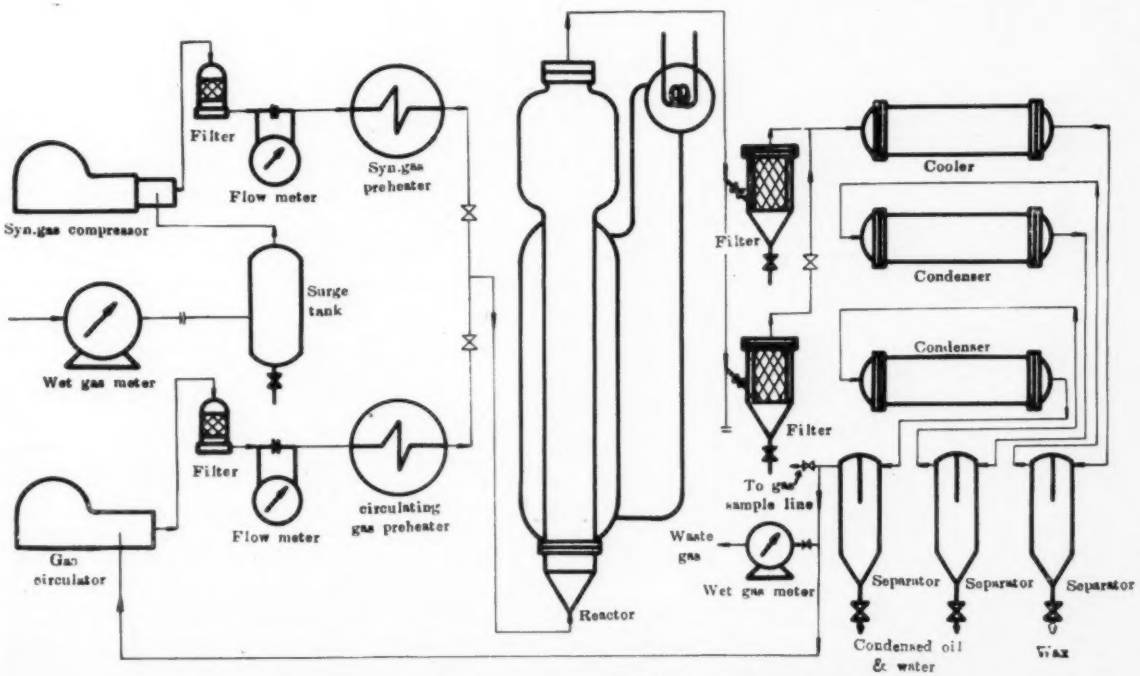


Fig. 2. Flow diagram of the pilot plant erected in 1953 and referred to above.

Table 2. Comparison of Different Methods of Analysis of Exit Gases

Sample	Method of analysis	Composition, vol. %								
		H_2	N_2	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_2H_4	C_3H_6	C_4H_8
01	CA	21.7	20.2	18.6	20.1	9.7	9.3	—	—	—
01	L	21.4	20.3	18.5	20.3	9.3	9.6	—	—	—
02	L	82.2			6.8	3.0	1.9	1.2	3.6	1.3
02	CS	81.6			6.6	3.1	2.1	1.2	3.5	1.7

CA = gas-solid chromatography, using active carbon as adsorbent.
CS = gas-solid chromatography, using silicia gel as adsorbent.
L = low-temperature fractionation using a micro column.

Table 5. Component Analyses of Oxygenated Compounds in the Condensed Aqueous Layer

Composition: / Type of catalyst:	Weight % of condensed water		Weight % of total oxygenates in condensed water	
	Nitrided	Nitrided and alkalised	Nitrided	Nitrided and alkalised
Component:				
Methanol	0.93	0.19	10.5	1.1
Ethanol	4.39	7.26	49.5	40.0
Propanols	1.87	1.48	21.1	8.2
Butanols and higher alcohols	0.65	0.41	7.3	2.3
Acetone	0.31	0.28	3.5	1.6
Butanone	0.19	0.14	2.1	0.8
Pentanones	0.17	0.04	1.9	0.2
Hexanones and higher ketones	0.01	0.02	0.1	0.1
Acetic acid	0.29	5.17	3.3	28.6
Propionic acid	0.09	1.14	1.0	6.3
Butyric and higher acids	0.06	1.96	0.7	10.8
TOTAL	8.87	18.09	100.0	100.0

Table 3. Properties of Primary Gasoline

1. Engler distillation:	
1st drop	39°C.
10%	53°C.
50%	78°C.
90%	152°C.
End point	177°C.
2. Vapour pressure mm. Hg	424
3. Octane rating:	
clear	62
plus TEL 1.3 gm./kg. oil	77
4. Bromine No. mg./gm. oil	1,110
5. Acid No. mg. KOH/gm. oil	28
6. Gum mg./100 ml. oil	2
7. Corrosion test	pass

Table 4. Gum Content of Primary Gasoline during Storage Test

Time	mg./100 ml. oil	
	Sample No. 1	Sample No. 2
0	<2	<2
3 months	<2	2.6
10 months	3.6	5.0
12 months	13.8	4.4

tained from two runs of 1,000 to 1,500 hr. duration, as well as one run performed in the small fluid unit on an alkalised catalyst. It can be seen that the durability of the catalysts was satisfactory and variations in the space velocity did not lead to marked changes in conversion. Both runs were terminated without any loss in operability. The shift of product distribution toward lighter fractions was noticeable. However, this change was considerable only in the initial period of synthesis. Similarly, the yield of methane increased rapidly during the first 500 hr., and remained constant thereafter. The increase in yield of ethane with time was only slight. The yield of oxygenates tended to decrease during synthesis.

Composition changes of the catalyst were analysed by taking samples from the reactor at regular intervals. The results were comparable with those reported by Anderson.[2] The displacement of nitrogen by carbon in the catalyst was clearly observed. This displacement action proceeded very rapidly in the first 200 hr. and levelled off afterwards. The (C + N)/Fe mole ratio remained constant during the course of synthesis. The O/Fe mole ratio, however, showed a gradual increase.

Hall and Taylor considered the back-mixing of gases in fluidised beds very undesirable and stressed the importance of the height-diameter ratio in scaling up the reactors.[17] It is felt that this point is somewhat overemphasised for processes using recycle operations, as recycle would bring the gas composition between bed inlet and exit close to each other, thus minimising the effect of any back-mixing. Assuming the synthesis reaction to be the first order, the decrease of conversion due to complete mixing was calculated to be 3.5% for a recycle ratio of 4. In our experiment gas samples were taken from various parts of the 6-in. reactor and the 1½-in. unit. Analyses showed that flow pattern in the 6-in. reactor approached that of complete mixing, while in the 1½-in. unit gas flow was essentially streamline. CO conversions in parallel runs performed in the two reactors differed by 3.4 to 4.6% which checked well with the predicted value.[18] The product distributions in parallel runs were also compared. Reproducibility was good, and if differences appeared, the larger unit gave better results. In the light of the above facts, it would be very unlikely that further scale-up of the reactor should bring any decrease in activity or selectivity.

Characteristics of products

The character of the gasoline fraction of a typical primary product is indicated in Table 3.[19] Its direct use as motor fuel should be adequate.

It should be noted that the octane rating of this material is fairly low and therefore the compression ratio of any vehicle which would use it without severe addition of tetraethyl lead would have to be low. The lead response is quite good, which indicates relative freedom from sulphur.

Storage tests were made and the increase in gum content is shown in Table 4. In sample 1 no gum inhibitor was added, while sample 2 contained 0.005% of N-N′-*p*-di-*sec*-butyl phenylene diamine. The data showed that improvement in stability was obtained through the addition of the inhibitor.

The synthesis product differed appreciably from that reported in the literature,[2] in that lower yields of oxygenated compounds were obtained. Over the wide range of process variables studied, the aqueous organic carbon never exceeded 10% of C_{3+} yield and the oxygen content in the oil layer was about 1%. Alkali addition to the catalyst, however, doubled the oxygenates yield.

Component analyses of oxygenated

compounds in aqueous and oil layers are given in Table 5. The analyses of oxygenates in the oil phase is now in progress.

Study of cobalt catalyst

Finally, we have also investigated the conventional Fischer-Tropsch synthesis, particularly the catalysts. Zhen[24] found that during the preparation of the catalyst a part of $CoCO_3$ reacts with the surface layer of kieselguhr forming surface complex, which exert a rather prominent influence on the activity, namely, an amount of 5 to 30% metallic Co in the form of surface complex is necessary for the improvement of the activity of the catalyst.

These catalysts, reduced and unreduced, were studied for their surface texture.[25] The surface area (B.E.T.) and number of pores of radius about 20 Å increase with the complex content. When the percentage of Co (complex) is larger than 30%, the isotherms of catalysts exhibit 'knife-like' desorption curves at $P/P_0 = 0.5$, corresponding to lower activity. When it is smaller than 30%, its isotherms exhibit narrow hysteresis loop, corresponding to normal activity.

With regard to the influence of preparation temperature, it was found that two kinds of catalysts having the same content of surface complex, but showing different activities, can be prepared at different temperatures, and those which were prepared at lower temperature exhibit better activity and contain fewer pores of 20 Å radius.[26]

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Scaling Up

This is the first book* dealing with the subject exclusively from the point of view of a chemical engineer. The book collects in one place the methods, both qualitative and quantitative, for predicting the performance of large-scale process plants from the results of small-scale experiments. The mathematics used is not too advanced and generally the results are reduced to simple equations which can be directly applied to practical cases.

Any doubt with regard to the importance of the subject is dispelled by a quotation at the very outset: 'Commit your blunders on a small scale and make your profits at a large scale.' This subject is bound to become considerably more important with the advent of the large-scale manufacture of new products or of existing products by new processes. A full-length book on the subject is particularly welcome since it will promote wider discussion at the universities besides serving as a useful reference to the practising engineer.

A great deal of the experimentation in chemical engineering has so far been of the trial-and-error type and this is not only time-consuming but also expensive. The authors point out the desirable modern trend towards refinement of experimental technique for getting accurate design data cheaply. Two factors contributing to this trend are application of statistical analysis and the use of model theory.

In the selection and the presentation of the material the authors have been guided by their long experience in a wide range of chemical and process industries. The opening chapters deal logically with topics such as similarity, dimensional analysis and other theoretical principles. The later chapters show the application of these principles to a wide variety of chemical engineering operations including filtration, heat transfer, packed towers, mixing equipment and chemical reactors. The last chapter deals in detail with the mathematical theory of analogue models. Some worked examples are also included to illustrate the application of the various principles. Not all of the unit operations and unit processes are dealt with, but no doubt there are many gaps in our knowledge. Also the arrangement of the sections dealing with practical applications appears to be somewhat arbitrary.

On the whole, the book is very well written and maintains a good balance between theory and practice.

O. P. KHARBANDA

*'Pilot Plants, Models and Scale-up Methods in Chemical Engineering,' by R. E. Johnstone and M. W. Thring. McGraw-Hill, 1957. Pp. 307. 71s. 6d.

To Authors of Technical Articles and Books

The Editor welcomes practical articles and notes on chemical engineering and related subjects with a view to publication. A preliminary synopsis outlining the subject should be sent to The Editor, CHEMICAL & PROCESS ENGINEERING, Leonard Hill House, 9 Eden Street, London, N.W.1.

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Nomogram:

Viscosity of Liquid Methyl Chloride

By D. S. Davis

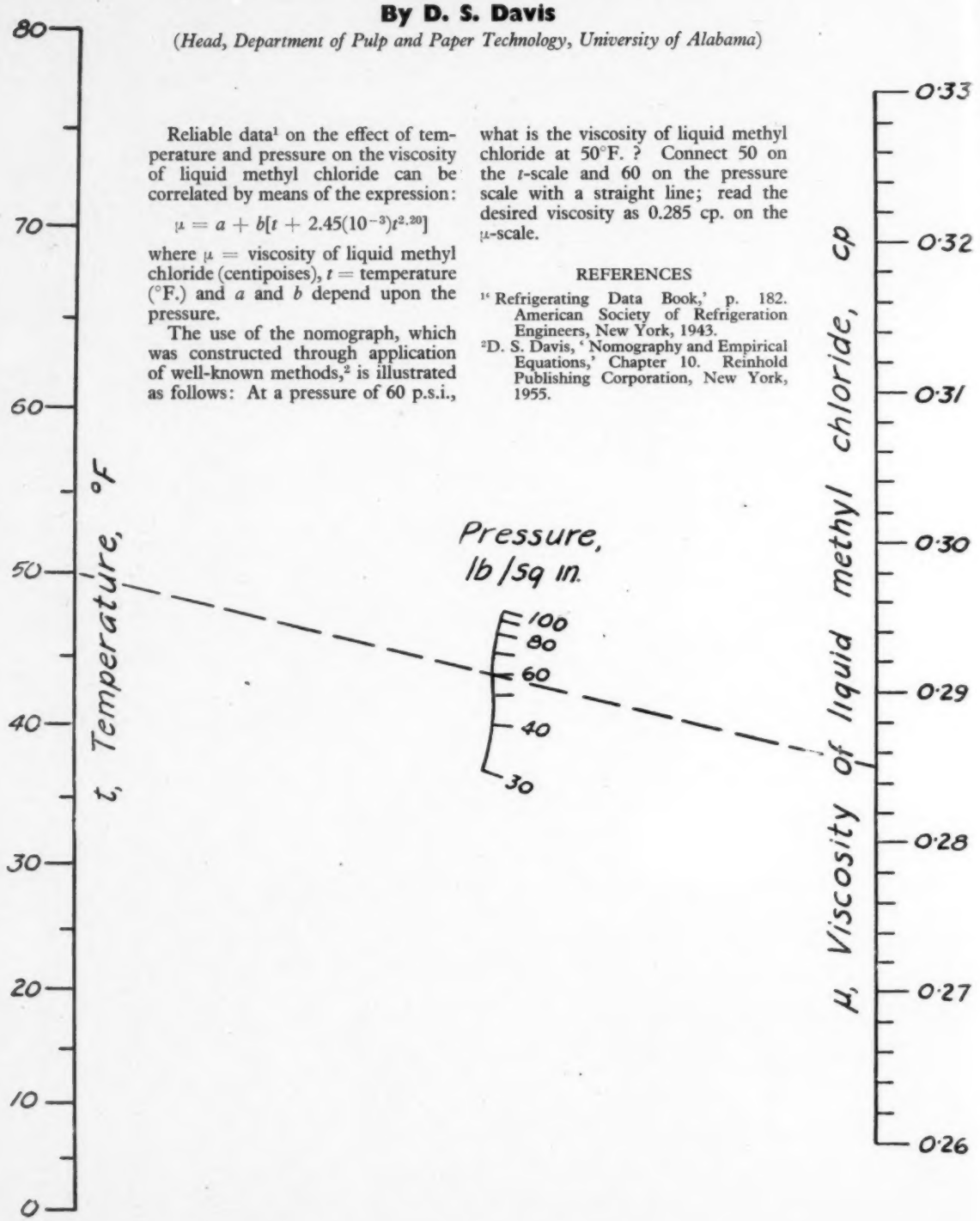
(*Head, Department of Pulp and Paper Technology, University of Alabama*)

Reliable data[1] on the effect of temperature and pressure on the viscosity of liquid methyl chloride can be correlated by means of the expression:

$$\mu = a + b[t + 2.45(10^{-3})t^{2.20}]$$

where μ = viscosity of liquid methyl chloride (centipoises), t = temperature (°F.) and a and b depend upon the pressure.

The use of the nomograph, which was constructed through application of well-known methods,[2] is illustrated as follows: At a pressure of 60 p.s.i., what is the viscosity of liquid methyl chloride at 50°F. ? Connect 50 on the t-scale and 60 on the pressure scale with a straight line; read the desired viscosity as 0.285 cp. on the μ-scale.



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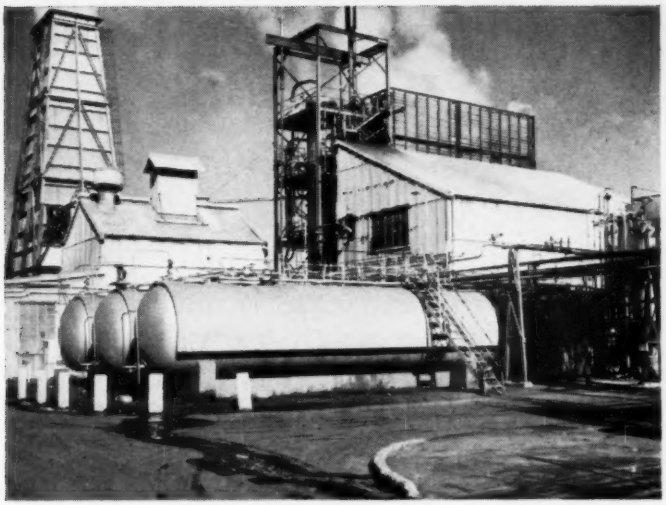
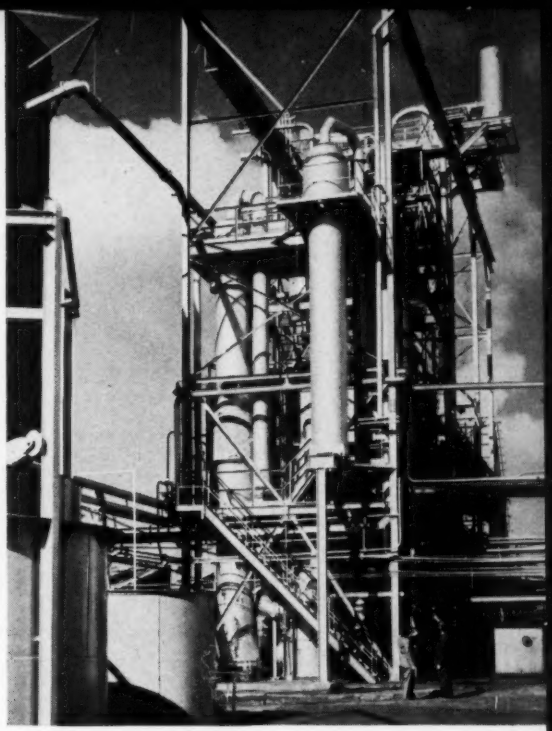




Australian Chemicals

A YOUNG and vigorous industry in a young and vigorous country is a good description of the chemical industry in Australia, where new plants are making the country less and less dependent on imported chemicals. Striking evidence of the industry's progress is provided by these pictures of the Deer Park, Victoria, facilities of Imperial Chemical Industries of Australia & New Zealand Ltd.

The company's activities are divided into four main groups, comprising manufacture of synthetic ammonia and explosives, dyes and plastics, and biological and chemical research. Ammonia, as one of the most widely used chemicals in industry, is one of I.C.I.A.N.Z.'s most important products. In the plastics field the company makes PVC.

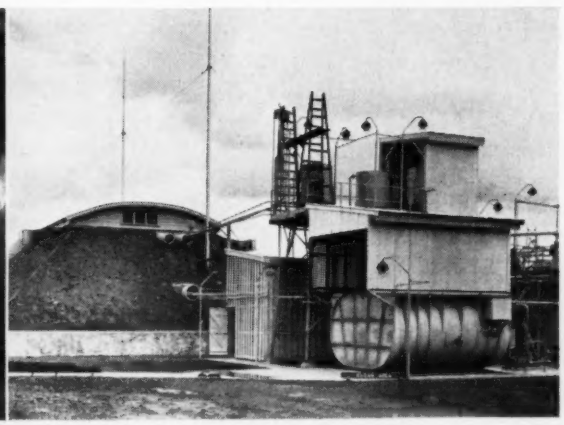
To cover its varied activities I.C.I.A.N.Z. has established an up-to-date research laboratory at Ascot Vale, Victoria. Deer Park, on the western outskirts of Melbourne, is the main manufacturing centre for Victoria.

Top left: **The ammonia oxidation plant, with storage tanks for liquid ammonia, at Deer Park, Victoria. The process produces 60% nitric acid used in the adjoining plant as basic raw material for the manufacture of commercial explosives.**

Top right: **Units of the ammonia synthesis plant at Deer Park, Victoria. In the foreground is the nitrogen purge gasholder, and in the rear the stainless-steel forced - draught water - cooling tower and hydrogen set.**

Bottom left: **Stainless-steel equipment for continuous manufacture of nitroglycerine at Deer Park, Victoria. Process is by remote control from operator's desk, at left. Cylindrical vessel in foreground is a nitrator, to left of which is an acid separator. At rear left are three washing vessels.**

Bottom right: **Eastern side of the nitration building, with service tanks in the centre and right foreground, units of the nitroglycerine process at Deer Park, Victoria.**



ADHESION AND ADHESIVES

Why some substances 'stick' together and others do not, and the physical and chemical phenomena which lie behind the successful bonding, by means of adhesives, not only of wood, paper, etc., but also metals, plastics and other materials are questions to which scientists have been finding the answers in recent years, for the benefit of engineers and all concerned with construction and manufacture.

By N. Pilpel, B.Sc., Ph.D.

THE use of new materials such as plastics, polymers and resins as insulating and protective coatings, and as materials of construction, has been largely responsible for developments in a field which, until quite recently, had been relatively neglected. Adhesives, it is true, had been used from very early times and there are records to show that glues derived from fish and animals were used for bonding wood and fabrics at least 3,000 years ago.

Similarly at quite an early stage in the textile industry 'sizes' derived from starch and from vegetable gums were employed to consolidate the fibres of wool and cotton, facilitating spinning and weaving and increasing the ability of the fibres to absorb different colours during dyeing processes.

But the compositions of adhesives and the methods of applying them had been completely empirical, recipes being handed down as closely guarded secrets, and until about 30 years ago there was virtually no theory on why certain materials were better adhesives than others and why, for example, glue would stick to wood but not to metal.

This state of affairs ended when industry was called upon to do two things.

Firstly to improve the properties of existing adhesives so that joints would be able to withstand the high stresses and exacting conditions that new design and practice involved.

Secondly, to develop entirely new adhesives that would stick metals, ceramics, glass and the wide range of plastic materials that were beginning to come into everyday use.

Table 1. Examples of Adhesion Between Immiscible Liquids

Liquid	*Adhesion to mercury ergs/sq.cm.*	*Adhesion to water ergs/sq.cm.*
Hexane ..	120	40
Carbon tetrachloride ..	150	56
Nitrobenzene	173	91
Oleic acid ..	191	90
Water ..	182	146
Mercury ..	960	183

Table 2. Work of Adhesion at 25°C. on Crystalline Solids

(in ergs/sq.cm.)

Liquid	*$BaSO_4$*	*SiO_2*	*$ZrSiO_4$*	*Graphite*
Water	610	720	970	295
Carbon tetrachloride	280	—	470	—
Benzene	210	220	330	—
Isooctane	—	—	240	—

Table 3. Relation Between Real and Apparent Area of Contact Between Two 'Flat' Surfaces[6]

Load (kg.)	*Real area of contact (sq.cm.)*	*Fraction of total area in contact*	*No. of points of contact*
500	0.05	1/400	35
100	0.01	1/2,000	22
20	0.002	1/10,000	9
5	0.0005	1/40,000	5
2	0.0002	1/100,000	3

Nature of adhesion

Different surfaces adhere to one another in different ways and both chemical and physical forces are involved. There have thus been many theories proposed on the nature of adhesion[1] which at first sight appear to be incompatible, since some concentrate on the physical and others on the chemical forces. In addition the term adhesion means rather different things to the pure scientist on the one hand and to the applied scientist on the other, and this has resulted in a good deal of confusion which, even now, has not been fully resolved.

To the pure scientist adhesion generally means an attraction between surfaces arising from electronic, covalent, or Van der Waal's forces which exist between neighbouring molecules. The first two lead to chemical bonds, the last to physical bonds.

Provided no chemical bonding has occurred, the work of adhesion between two surfaces, W_{12}, is a measure of the amount of work that is required to separate them perpendicularly from each other. When this separation is performed in air

$$W_{12} = \gamma_1 + \gamma_2 - \gamma_{12} \quad \text{(in ergs/sq.cm.)} \qquad (1)$$

In this equation, γ_1 and γ_2 are the surface tensions of the two surfaces and γ_{12} is the interfacial tension between them.

In the case of one liquid spread upon another, *e.g.* oil on water, the quantities γ_1, γ_2 and γ_{12} can be deter-

mined directly by measurement and some typical values for the work of adhesion between immiscible liquids is given in Table 1.[2]

But in the case of a liquid 1 spread upon a solid 2, the quantity γ_2 is not directly measurable, although it can be shown that

$$W_{12} = \gamma_1(1 + \cos\theta) \quad \ldots\ldots\ldots \quad (2)$$

where θ is the angle of contact between the liquid and the solid (Fig. 1).

Values of the work of adhesion between certain liquids and solids are given in Table 2.[2]

Behaviour of solid particles in a liquid

Using the word in this limited sense there are a number of ways in which it may be shown that physical adhesion occurs between the surfaces of solids. For example, when particles of a solid are immersed in a liquid, the extent to which they dissolve or disperse depends on the relative magnitudes of the forces causing them to adhere to each other and those causing them to adhere to the liquid. When the former predominate, the particles do not dissolve, but remain suspended or as a sediment. When adhesion to the liquid predominates, on the other hand, the particles either dissolve completely or spread out in the form of a colloidal dispersion. Very considerable changes in the magnitude of the adhesive forces can be produced by treating the particles with materials which are adsorbed on to their surfaces. Thus anionic detergents, *e.g.* sodium lauryl sulphate, facilitate the dispersion of otherwise insoluble powders and are thus useful as wetting and washing agents, while cationic detergents, *e.g.* cetyl trimethyl ammonium bromide, have the reverse effect and have been used for getting dispersed particles to adhere to solid surfaces, *e.g.* in coating woollen fabrics with particles of latex rubber to make them waterproof.[3]

Similar effects on the strength of the adhesive forces between solid particles in a liquid can also be produced by the addition of electrolytes or certain colloids to the system. Verwey and Overbeek have recently developed a theory[4] which explains reasonably well the physical properties of some of these systems and the tendency of the individual particles to coagulate in terms of the electrostatic forces which operate between them. Much other work has been reported on this subject,[5] but it would be misleading to suggest that the above theory, or any of the others which have been proposed, are entirely satisfactory.

Adhesion between solid surfaces

Direct adhesion between solids in bulk can also be demonstrated. Normally the surface of a solid is not flat, for even after careful grinding and polishing there still remain pits and asperities on the surface whose height may vary from a few angstrom units up to several hundredths of a millimetre.[6] In addition, all surfaces which have been exposed to the atmosphere are normally covered by adsorbed films of moisture and gas. These may be no more than 1 molecule thick, but cling very tenaciously to the surface and, in fact, can only be removed by heating the surface to a high temperature at a pressure less than about 10^{-7} cm. of mercury. The irregularities and the adsorbed films both serve to keep the surfaces apart, although for most practical purposes it is the former which have the greatest effect.

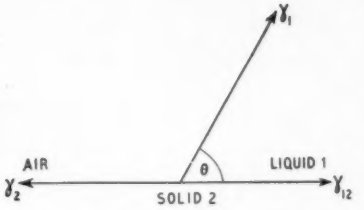


Fig. 1. Point of contact between air, a liquid and a solid.

Fig. 2. Contact of solid surfaces.

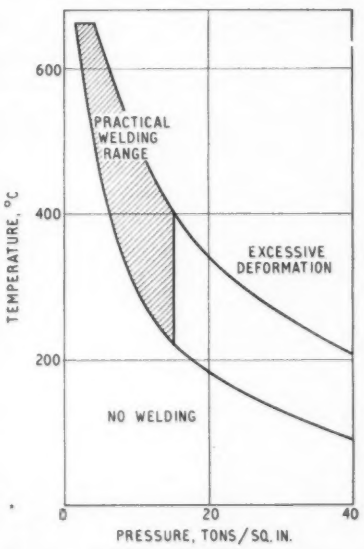


Fig. 3. Cold welding of aluminium (after R. F. Tylecote)

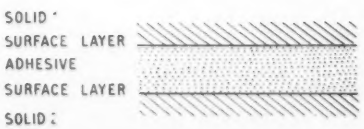


Fig. 4. Structure of an adhesive joint.

When two so-called flat surfaces of steel, 21 sq. cm. in area, were carefully cleaned and pressed together under different loads, it was found[6] that the real area of contact was only a very small fraction of the apparent area of contact. This is shown by the data in Table 3, the surfaces being pictured schematically in Fig. 2.

At the real points of contact there is apparently sufficient mechanical stress to rupture the adsorbed films and, according to Bowden and Tabor, welded bridges are formed between the surfaces. (An alternative theory has been proposed by Schnurmann.[7]) But, because there are relatively few of these welds, even when the area in contact is apparently large, the overall attractive force between the surfaces is not great enough to hold them together. However, if the pressure between the surfaces is raised, a point is eventually reached when the irregularities become sufficiently deformed for a considerable area of real contact to be established. The pressure needed depends on the initial smoothness and cleanliness of the surfaces and also on its temperature, but once widespread contact has been effected the surfaces adhere to each other with great force, the bonds now being essentially chemical.

This is the basis of a new technique —cold welding—which is coming into use in the aircraft and motor-car industries for sticking together components made of aluminium and certain soft alloys. The initial cleaning and preparation of the surfaces for cold welding is most important; for aluminium, degreasing with solvents followed by brushing with fine steel wire is recommended. Thereafter there is a direct correlation between the temperature of the surfaces and the pressure which must be applied to effect the weld and this is shown graphically in Fig. 3.[8]

Function of an adhesive

We consider now adhesion when the word is used in its more general sense. For to the applied scientist adhesion implies the use of an adhesive.

An adhesive joint between two solid surfaces consists of five regions and these are shown in Fig. 4.

Several stages are involved in the formation of the joint. Firstly the two surfaces must be smoothed and cleaned. The adhesive is applied as a liquid, although in some cases a powder may be employed which is afterwards converted into a liquid by heating. The adhesive is then rendered viscous by cooling or by allowing the solvent in which it has been dissolved to evaporate.

Up to this point mainly physical forces have been operating and for success the works of adhesion between the adhesive and the two solid surfaces should be high. But in the final stage of making the joint, when the adhesive is setting, chemical reactions between the adhesive and the two surfaces usually occur. (An exception is in adhesive tapes when the bonding appears to be due primarily to physical forces.) The bonds which ultimately hold the two surfaces together are therefore both physical and chemical in nature and the strength of the joint is dependent on the contributions of each. But there are other very important factors which determine the strength of the joint and its ability to stand up to operating conditions. For example, some adhesives, like animal glue, set to hard, rather brittle solids. Others, such as those based on rubber, are tough rather than hard and retain flexibility. The latter are thus better than glue for withstanding repeated vibrations and the stresses occasioned by sudden changes in temperature. Again glue, unlike many synthetic adhesives, is susceptible to attack by moisture and bacteria and when a joint made with glue is exposed to hot, humid conditions the layer of adhesive is gradually decomposed.

The thickness of the adhesive layer considerably affects the strength of the joint, and the work of numerous investigators[9, 10, 11] has clearly shown that the thicker the layer the weaker the joint. Thus the tensile strength of a joint, using paraffin wax between metal surfaces, was 24.6 kg./sq.cm. when the layer of wax was 57μ thick and only 14.8 kg./sq.cm. when the layer was 540μ thick.[11] The shear strength of the joint decreases similarly and this is shown in Fig. 5.[12] These findings are in qualitative agreement with Stefan's theory[13, 14] on the separation of surfaces immersed in viscous fluids, although factors other than those considered by Stefan, namely chemical forces, also contribute to the strength of the finished joint.

Glue

It has already been mentioned that animal glue was the first adhesive to be widely used. Glue (or gelatin) is obtained by treating the bones, horns and skins of animals with steam or boiling water, this converting the insoluble collagen into the soluble protein, gelatin. Gelatins can be of various grades depending on the source of the collagen, the duration of the extraction treatment, the *p*H of the water, etc., but essentially the gelatin molecule consists of 18 amino acids linked together by peptide bonds. Of these acids glycine, proline, hydroxyproline, arginine and alanine are the chief.[15]

When a solution of gelatin is cooled it changes rapidly from the liquid state into a jelly, the process being ascribed to interlinking of the molecules to form a network structure. The tensile strength and rigidity of the jelly depend on the grade of gelatin, on its concentration and on its temperature and, for commercial purposes, gelatins are sold on the basis of their jelly strength. This property is conveniently determined on the Bloom Gelometer, which measures the weight which is needed to depress a plunger 12.7 mm. in diameter to a depth of 4 mm. into a jelly at 10°C. containing 12.5% of the particular grade of gelatin. In this country the grades of glue which are used for sticking wood run from about 50 to about 200 g. Bloom, but in the U.S. grades up to about 400 are used.

Animal glues are widely employed in the wood industry, *e.g.* for sticking furniture, musical instruments, toys, etc.; in the paper industry, *e.g.* in bookbinding, advertising posters and gummed paper; and as sizings for fabrics, wall plasters, straw hats, etc. An important factor contributing to their popularity is their relatively low cost. Nevertheless, animal glues suffer from a number of disadvantages which include poor resistance to moisture and to bacterial attack. Glued joints, too, are often rather brittle, although this difficulty can now be overcome by adding glycerine to the glue. But probably their greatest drawback is the fact that there are now very many materials of construction to which animal glues will not adhere. Of these the chief are metals and plastics. It is probably true to say that the need for adhesives for these two classes of materials was primarily responsible for the development of the so-called synthetic adhesives.

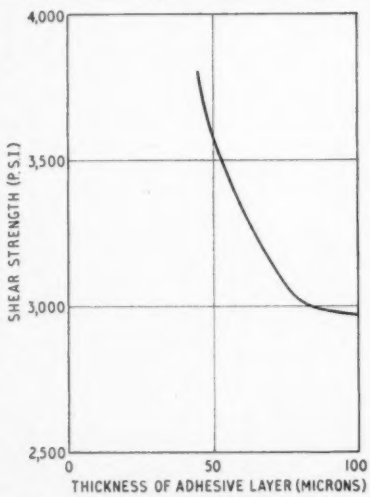


Fig. 5. Effect of adhesive thickness on shear strength.

Synthetic adhesives

Synthetic adhesives now include a very wide range of chemical substances,[14] but, broadly speaking, they may be classified under two main headings.

First, there are the thermoplastic adhesives. These include cellulose esters and ethers, alkyd and acrylic esters, polyamides and derivatives of polystyrene. The basic structures of some typical thermoplastic materials are shown in Fig. 6.

Thermoplastic adhesives soften on heating and harden again on cooling, the process being reversible provided the decomposition temperature of the material is not exceeded. In many cases they are applied in the molten state, the setting of the joint then being due simply to solidification of the adhesive layer when it cools. But in other cases it is more convenient to apply the adhesive in the form of a solution, the setting then being due to evaporation of the solvent, or to its diffusion into the surfaces concerned.

It is important that unevaporated solvent should not remain in the finished joint, since its presence may seriously weaken it. For this reason it is customary to employ volatile solvents such as toluene, methyl ethyl ketone, acetone and various esters and, generally, to air-dry the coated surfaces before assembling. The length of the drying period must be controlled for optimum results. Thus in one case,[16] when polyvinyl-acetate-coated surfaces were air-dried for 10 min. at room temperature, the shear strength of a joint rose from 100 to about 175 p.s.i., but when drying was allowed to proceed for 30 min. the final strength was only 60 p.s.i.

(a)	Methyl methacrylate	$CH_2=C(CH_3)COOCH_3$
(b)	Vinyl acetate	$CH_2=CHCOOCH_3$
(c)	Styrene	$C_6H_5CH=CH_2$

Fig. 6. Structural units of thermoplastic adhesives.

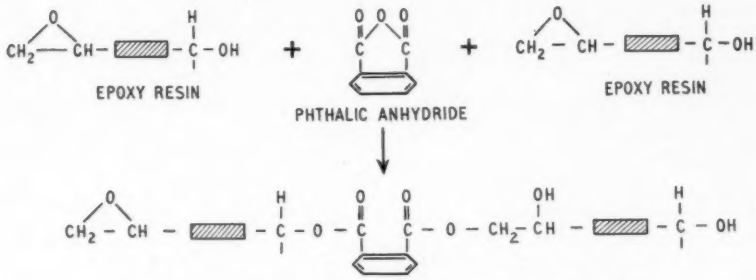


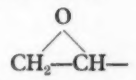
Fig. 7. Action of phthalic anhydride on an epoxy resin.

While thermoplastic adhesives are now commonly used for sticking together wood, leather, glass, plastics and, to a lesser extent, metals, and are quite satisfactory for most domestic purposes, they are not generally as suitable for industrial use as the second class of synthetic adhesives — the thermosetting type. There are a number of reasons for this, the most important being that thermoplastic adhesives tend to flow when subjected to continuous stresses, are softened by heating, and are dissolved by organic solvents.

Thermosetting adhesives do not suffer from these disadvantages and are therefore preferred when heavy loads and otherwise exacting conditions have to be met.

Thermosetting adhesives are characterised by the fact that, under the influence of heat, or reagents, they are converted from viscous liquids or resinous solids into tough, infusible substances which are insoluble in most organic solvents and which are largely unaffected by water, acids and alkalis. The setting process, which is irreversible, is due to the formation of cross-links between the different parts of the molecule. Thus the action of phthalic anhydride in promoting cross-linking in an epoxy resin is shown in Fig. 7.[17] For simplicity only the active groupings in the latter substance are shown, and only the first stage of the reaction. For clearly this can be repeated a number of times as more molecules of phthalic anhydride link on to the structure.

It is the presence in this structure of the ethoxy groupings



and the hydroxyl groupings —OH which enable an epoxy resin to adhere strongly to both polar and to non-polar surfaces. For at these points strong chemical bonds are formed between the adhesive and appropriate groupings in the surfaces concerned.

The number of thermosetting adhesives that is now available is very large. It includes the phenol, resorcinol, urea and melamine formaldehydes, derivatives of furan and polyurethane, and epoxy and silicone resins. The phenol and urea formaldehydes first came into use in the 1930s, but the epoxy and silicone resins are of more recent development and have only been available on the domestic market for about 10 years.

They have certain particularly valuable properties. Thus the silicone adhesives are particularly stable towards moisture and temperature and can be heated to over 200°C. without ill effects.[18] The epoxy resins, when blended with synthetic rubbers, form extremely strong bonds with metallic surfaces, the bond strength being comparable to that of a rivetted or welded joint. These adhesives have been used in aircraft manufacture for joining aluminium stiffeners to the metal skin on the wings and fuselage and, in certain cases, notably the De Havilland Comet, for joining main spars, etc.

Conclusion

Glue and vegetable gums are still the most widely employed adhesives, although over 60,000 tons of sodium silicate are also used annually in Britain, particularly for paper and fibre board, and for sticking glass, mica and asbestos when these materials are to be subjected to high temperatures.

In the last 30 years synthetic adhesives have gradually replaced conventional materials in a number of fields. Prior to this the methods of formulating adhesives and assessing their properties were largely empirical. Moreover it was not clear how an adhesive actually worked, the most commonly held idea being that its main function was to penetrate into the surfaces and form tentacles which were essentially mechanical in their action.

Undoubtedly this does occur. But now the significance of chemical bonds between certain groupings in the adhesive and others in the surfaces has been demonstrated, and this has enabled the whole subject to be placed on a scientific basis.

This should help greatly in the solution of the many problems of adhesion which currently confront scientists, engineers and craftsmen in fields as diverse as furniture making, book-binding, aircraft manufacture, textiles, plastics and ceramics.

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Company News

The demand for *Terylene* for a wide range of clothing, personal and industrial uses continues to increase, and an extension of plant capacity from 22 million to 30 million lb. p.a. is under construction. Plans are well advanced in the Fibres Division of I.C.I. for a further increase of capacity of 20 million lb. p.a. of *Terylene* fibre, involving the building of an entirely new plant at Wilton which is expected to cost, with supporting plants, approximately £20 million.

On the other hand, the progress of the *Ardil* project has been disappointing, and it has been decided that manufacture shall cease in the near future.

*

A further order for glass pipeline and fittings for the Polymer Corporation of Sarnia from the Meade Laboratories at Richmond Hill, Ontario, is announced by Q.V.F. Ltd. This is the second such order from the Meade Laboratories this year. An earlier order, valued at £10,000, was the largest consignment of glass pipeline ever shipped from the United Kingdom.

*

British Tyre & Rubber Co. Ltd. has announced a change of its name to BTR Industries Ltd.—a title designed to emphasise its relationship to industry in general as British thermoplastic and rubber manufacturers. The *BTR* trademark will continue to identify the products marketed by the company.

*

BX Plastics Ltd. have announced the purchase by them of Extrudex Ltd., Bracknell, Berks., manufacturers of chemical plant and tubing in rigid vinyl material, who will continue to operate as a separate organisation.

*

Minnesota Mining & Manufacturing Co. Ltd. have a new seven-storey office block at Wigmore Street, London.

*

At a recent ceremony in Greenford, Middlesex, Mr. E. C. Vorlander, managing director of Honeywell-Brown Ltd., laid the foundation stone for the 483,000 cu. ft. of modern architecture which will accommodate the administration of all divisions—industrial instrumentation, thermostatic controls and micro switches—when the new head offices of the company are opened in June 1958.

*

Costain-John Brown Ltd., who are engineering and constructing Messrs. Chemstrand's £3½-million *Acrilan* synthetic fibre plant at Coleraine, Northern Ireland, recently held a reception in Belfast to mark the ending of the civil engineering phase on the plant and also the establishment of an office in Ulster.

*

Pilkington Bros. Ltd. have announced that Ashdowns Ltd., of St. Helens, their subsidiary manufacturing plastics, will be closed down by December 31, after outstanding trade commitments have been met.

Although extensive changes have only recently been completed, Pilkington Bros. Ltd. consider that long-term prospects are not sufficient to justify the further substantial investment which would be necessary. They have accordingly decided it would be of greater benefit to the Pilkington Group to employ these resources in their main business of glassmaking.

*

Pennsalt Chemicals Corporation (U.S.) has announced the formation of a wholly-owned subsidiary in Canada, to be known as Pennsalt Chemicals of Canada Ltd.

*

The increasing demand for plastics machinery of all kinds has prompted F. J. Edwards Ltd. to set up a new division to handle a comprehensive range of this type of machinery.

At the recent British Plastics Exhibition they were showing and in many cases demonstrating a wide selection of the latest Continental machines, having secured the sole agency in the U.K. for the products of many of the leading manufacturers from abroad, including W. H. Hillesheimer, J. Sandt A.G., A. Schwalbach K.G., G. Siempelkamp, Albert Stubbe, Paul Troester A.G. and Arno H. Wirth.

*

The Coppee Co. (Great Britain) Ltd. announce that they have been successful in obtaining a contract for approximately £1¼ million for coke-oven, chemical by-product and coal-preparation plant for the Rhodesian Iron and Steel Co. Ltd.'s steelworks extensions at Que Que, Southern Rhodesia. This contract has been obtained through the operation of the associated company, Powell Duffryn-Coppee Ltd.

C.P.E. COST INDICES —LATEST FIGURES

For those keeping a record of our cost indices the two latest figures are: Plant Construction Cost Index, July, **169.4;** Equipment Cost Index, July, **160.6.** The latter figure is the same as in June. Both indices are based on June 1949 = 100.

VACUUM COLUMN ON THE MOVE

This 26-ton steel vacuum column was designed by Head Wrightson Processes Ltd. for erection at the Weaste refinery of Berry Wiggins & Co. Ltd. The 90-ft. column is seen approaching Marble Arch after leaving the manufacturers, G. A. Harvey & Co. (London) Ltd.

WHAT'S NEWS about

★ Plant
★ Equipment
★ Materials
★ Processes

This illustrated report on recent developments is associated with a reader service that is operated free of charge by our Enquiry Bureau. Each item appearing in these pages has a reference number appended to it; to obtain more information, fill in the top postcard attached, giving the appropriate reference number(s), and post the card (no stamp required in the United Kingdom).

Crushing without rubbing

In the No. 110 *Kue-Ken* jaw crusher manufactured by Armstrong Whitworth (Metal Industries) Ltd. flood lubrication permits cool running at 300 to 350 crushing strokes/min. This means greater capacity and, with the direct crushing stroke imparted, an evenly crushed product. The elimination of much wasteful rubbing also means longer life to the jaws. The light, strong pitman and relatively flat toggles are designed to give greater leverage conducive with low bearing pressures.

Designed with the same object as the jaw crusher of 'crushing without rubbing,' the 36-in. *Kue-Ken* gyratory crusher is a light, compact and powerful machine which is ideal for working in conjunction with a jaw crusher of the same range, making available a complete primary and secondary crushing system. It also features a built-in lubrication system and overload safety device. **CPE 729**

All-plastic check valve

What is claimed as the first all-plastic lift check valve has been introduced by the Walworth Co. (U.S.). Body and components of the new valve are made of normal-impact rigid PVC to provide high corrosion resistance to alkalis, acids, inorganic salt solutions and other corrosive flow material. A highly durable PVC spring positions the disc to assure quick and complete shut-off.

The new PVC check valve operates successfully at pressures up to 150 p.s.i. at 75°F. Complete shut-off was obtained with the valve during and after 2 million continuous cycles under 125 lb. of air and 50 lb. of water. **CPE 730**

Metropolitan-Vickers mass spectrometer at the B.T.H. laboratories, Rugby.

Analysis of inorganic solids

While the main applications of the mass spectrometer have been to the isotopic assay of gases and liquids and the chemical analysis of volatile inorganic and organic compounds, one of the most striking developments in recent years has been in the analysis of inorganic solids. Two special types of mass spectrometer have been designed by Metropolitan-Vickers Electrical Co. Ltd. for this purpose—the MS5 for the determination of isotope ratio using the surface ionisation technique, and the MS7 for the analysis of impurities using the spark ionisation technique.

The MS5 is a 12-in.-radius, 90°-sector, single-focusing mass spectrometer for use with either the single- or triple-filament surface ionisation technique. Two particular features of the instrument are a sliding-bar vacuum lock system, which enables the sample to be introduced into the instrument in less than a minute, and an ion collector system, which provides for the simultaneous availability of a normal collector and an electron multiplier. A resolving power of at least 300 can be obtained.

The type MS7 mass spectrometer is a double-focusing instrument of the Mattauch type, in which positive ions, representative of the sample composition, are produced when a high-voltage spark occurs between two electrodes formed of the sample material and placed close together in vacuum. After passing first through an electrostatic analyser and then through a magnetic analyser the ions come to focus according to their mass as a series of lines on a photographic plate. **CPE 731**

Rubber hose cuts conveying costs

A considerable saving in pipe replacement and maintenance costs has been effected at the N.C.B.'s Lynemouth coal-preparation plant by the use of a special heavy-duty rubber hose to convey abrasive magnetite. Still in service after 18 months, this *Fulflex* hose, as it is called, has already lasted over four times as long as the previous installation—representing a saving of some 150% of its cost—and is reported by its manufacturers, British Tyre & Rubber Co. Ltd., to be showing little sign of wear to date.

The 12-ft.-long, 12-in. bore of *Fulflex* hose concerned was installed in December 1955 between a primary drainage screen and surge tank to replace two bends and 4-ft. length of mild-steel piping of the same diameter and $\frac{3}{8}$-in. wall thickness. It was examined on March 31, 1956, and again in May 1956 and, although little wear was observed, the hose was rotated through 30°—an operation taking only a matter of minutes because of the spigotless construction of the hose. The users are carrying on this process of rotation at six-month intervals and the hose will eventually be reversed end-to-end to give maximum life.

The mild-steel bend and pipes previously used were holed after only four months' service and required patching —frequent leaks occurring during the operational period.

CPE 732

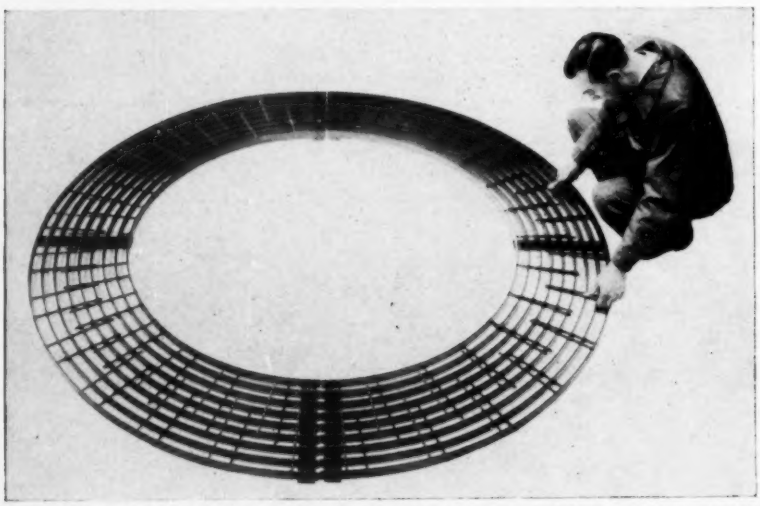
Photoelectric colorimeter

The function of the *Weka* photoelectric colorimeter, produced in Germany by W. Kauhausen, is based on the absolute-colorimetric measuring method, *i.e.* analysis without a standard solution. Due to novel principles of construction, fluctuations of the light output of the lamp and variations of the photocell sensitivity have no influence on the measurement. In spite of its high accuracy the colorimeter is very simple to handle. The measurements can be performed in brightly illuminated rooms. The measuring photocell is optically compensated and a reading scale with 1,000 divisions and of a total length of about 1 m. is available. This is an unusually large measuring range for colorimeters, which makes a much more accurate reading possible than on the short scale of a needle galvanometer.

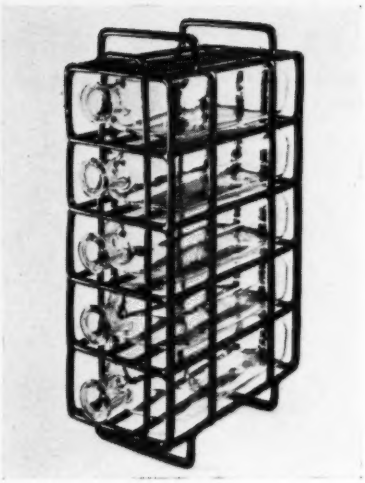
All results are reproducible to about one division of the scale, and an accuracy of 0.1 to 0.2% for measurements of moderately coloured solutions is secured. The measurement requires about $\frac{1}{2}$ min./sample. Because of its high accuracy, check measurements are usually not necessary, which means a considerable saving of time when precision requirements, especially in series measurements, are reduced.

The instrument can be equipped with recently developed accessories for flame photometry and spectrophotometry.

CPE 733



'Flowforge' open steel flooring forming a circular panel, fabricated in two half units from serrated-edge steel rings.



PLASTIC-COATED CRATES

Shown here is a specially designed crate for holding poliomyelitis vaccine bottles. The culture is grown in the bottle, removed and then the crates are sterilised in concentrated H_2SO_4 and finally autoclaved at 120°C. Manufactured by Durable Plastics Ltd., these crates are coated with high-density polythene, which has been found in practice to withstand these conditions repeatedly. The polythene coating has a threefold purpose: to make the steel framework corrosion-resistant; to cushion the bottles and prevent damage; and to reduce noise. **CPE 734**

Industrial timing device

Now being marketed is a new type of industrial process timing meter which is portable and claimed to be highly accurate. It registers in minutes, seconds and tenths (decimals) of a second on three separate and distinctive dials, so that misreadings cannot arise. Another feature is that the decimal hand cannot stop between strokes on the split second dial and accordingly 'dead - on - register' is always indicated and the reading always correct.

Sturdily constructed, the device is shockproof and has a seven-jewel lever movement.

The instrument works on a three-pressure principle: the first pressure on the button starts the hands; the second pressure instantly stops them; and a third returns them to zero. The T.D.50 will time operations up to 61 minutes (Industrial Timing Instruments). **CPE 735**

Stepless power control

For a great many automatic processes in which electric power is used, stepless control of the voltage or current is necessary, particularly in the case of process control, in which the quality of the product depends upon adherence to a preset cycle.

Where appreciable amounts of power are involved, the electronic control gear provides the brain, and a newly developed stepless regulator provides the brawn for controlling the power. The regulator is a continuously tapped auto transformer with graphite rollers, making contact over the whole range of its leg voltage. For remote and automatic control, a driving motor is incorporated. The contact movement has very low inertia, thus permitting high speeds of operation.

With the many devices now available, the necessary reference can be established for the control of temperature, speed, voltage, current, weight, pressure etc., but whatever reference is used, the interpretation of the signal by the regulator controlling the power must be correct.

This new regulator does not affect wave form or power factor, and does not introduce interference into the circuit. This feature is invaluable for such applications as sintering, and the current is used to predetermine the temperature over the sintering cycle. If the current reference is sinusoidal, departures from this function result in r.m.s. wave shape of irregular form, and the temperature maintained by the regulator is not uniform throughout the sintered bar.

The regulator is produced by Brentford Transformers Ltd.

CPE 736

Open steel flooring

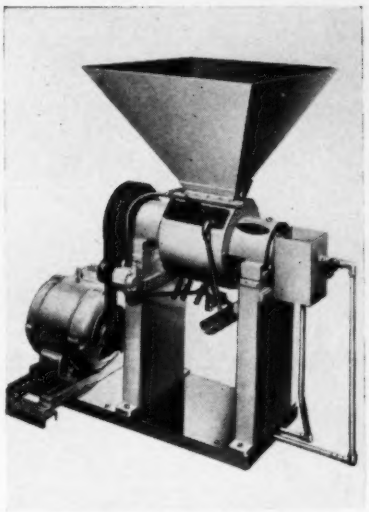
Flowforge flooring is one type in a range of open steel and aluminium flooring systems. It is an electrically forge-welded flooring claimed to have a high strength/weight ratio with maximum light-passing and ventilating capacity. It is produced in stock panels 20 ft. × 3 ft. and these, together with stair and ladder treads, are available in various sizes from Fisher & Midland Ltd.

An interesting development is circular panels measuring 6 ft. 6 in. to the outside edge, which have been produced to form circular walkways on tank cars. The circular panel is fabricated in two half units from serrated-edge steel rings spaced and held in position by forge-welded twisted bars spanning six serrated rings in lattice pattern, this method of construction being carried out on top and bottom faces.

CPE 737

Liquid mill

The *Multifold* liquid mill has been specially designed for the efficient wetting and refining of pigment particles and is of the roll type, with the roll running in an enclosed cylinder constructed in six sections. Between four of these sections, four pairs of concave refining blocks are fitted over the periphery of the roll, with between the blocks a channel of 1 mil.



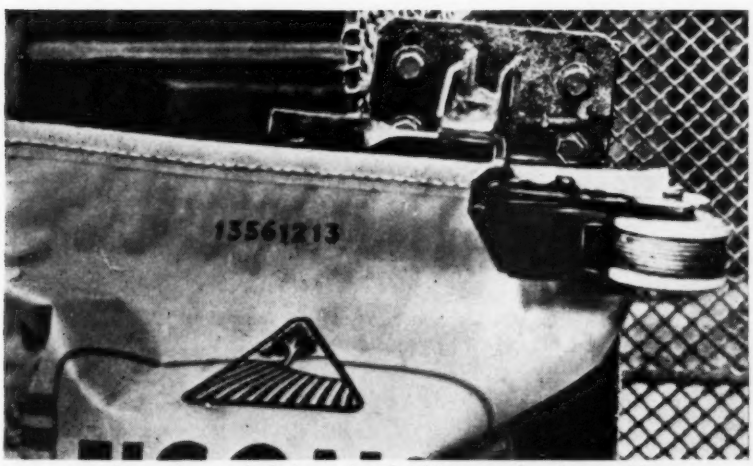
'Multifold' liquid mill.

The refining blocks are fitted between the sections and are of two thicknesses, the thicker being the actual refining block, and the thinner the collecting block. Pressure can be applied to both blocks. The mill is at present made in two standard sizes, 20 gal. and 60 gal., with cylinders of cast iron or steel with polished interior. Drive is direct by V-belt from suitable motors or a line shaft. Wm. Gardner & Sons (Gloucester) Ltd. are the suppliers. **CPE 738**

Sack marker

A method has been developed for coding sacks whilst they are travelling on a conveyor. The machine consists of a printing roller and a backing roller, pivoted on a spring-loaded arm, the machine being friction driven. The whole unit is mounted on a backing plate ready for fitting to existing lines.

The inking unit consists of a felt reservoir roller and a rubber transfer inking roller. Rubber type is used and the machine is adjustable for a printing length of up to 10½ in. Makers: Mark O'Print Ltd. **CPE 739**



A moving sack being printed with a number by machine.

Pneumatic pilot valves

The 'nerves' of a pneumatic control circuit are the small pilot valves which servo-operate larger automatic valves controlling the actual cylinders. Pilot valves recently introduced are

based on the linear slide valve principle and are of simple, rectangular shape, so that they can be mounted in confined spaces. They are produced from brass and stainless steel, and, according to the makers, Midland Pneumatic Ltd., corrosion is prevented completely.

Many types of alternative operation are available, including plunger, hand lever, ball, lever roller, foot, pad, micro-pilot, double and single air. Most of them are arranged for spring return action, this being obtained from a long, stainless-steel spring of low maximum stress and rating. **CPE 740**

Powder filling

A new *Multiple* filling machine has been designed with a view to speeding up the handling of free-flowing powders and granular materials. This machine, it is claimed, will fill cartons, cans, bottles etc. at a speed of from 100 to 120/min. A variable-speed control has been included to ensure that the filling operation keeps pace with other plant working in unison. There is also an automatic trip device which prevents the discharge of the material in the event of a delay in the supply of containers arriving at the filling machine.

An advantage is that the amounts filled can be fractionally increased or decreased while the machine is running.

To prevent possible contamination, all parts of the machine coming into contact with the product are made of stainless steel.

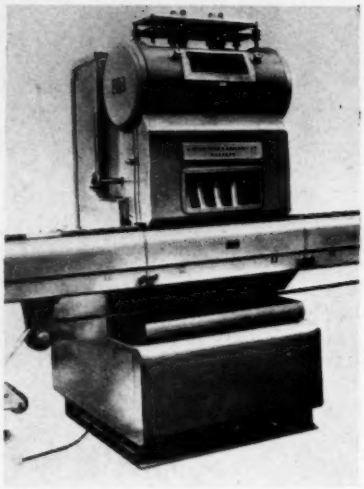
The *Multiple* is fitted with automatic conveyor feed and can be linked with box-making to make the process fully automatic. **CPE 741**

Hydraulic-pressure pump

With a theoretical ratio of air to hydraulic pressure of 1: 694, the *Airhydropump* made by Charles S. Madan & Co. Ltd. is for generating pressures between 25,000 and 55,000 p.s.i., powered by a normal shop airline up to 100 p.s.i. It is particularly suitable for all forms of hydrostatic testing in the pressure range mentioned, and for many manufacturing processes in the steel, chemical and allied industries.

For handling this very high pressure, the manufacturers have designed and fully tested a range of hydraulic control valves, pressure release valves and non-return valves, together with a series of pipeline couplings, tee pieces and other fittings. A striking feature of the control valves is the ease of operation even at full pressure.

The size of this new pump is $12\frac{1}{2}$ × 44 in. floor space × 18 in. high. It is portable, compact and fully automatic in operation. **CPE 742**



Machine for the automatic filling of powders and granular materials into containers.

Valve with wax-filled elements

A new coolant valve, the *Waxtrol*, embodies powerful wax-filled elements and has been specially designed for use with the largest diesel engines in marine, traction and stationary plants.

A special wax, of such a composition that a change in state occurs at the operating temperature, is sealed in a container in the operating element. This change of state results in a rapid increase in volume and power output. The expansion of the wax actuates the valve unit by extruding a flexible plug into a reduced diameter in the piston housing, thus magnifying the movement of the piston, which overcomes a return spring and moves the valve upwards against a fixed seat.

The inlet port is connected to the inside of the cylindrical valve and the coolant is passed either over the top of the cylinder to the by-pass or under the cylinder to the heat exchanger. A standard-size element is used providing a movement of 0.350 in. for a change in temperature of 25°F. The number of elements used depends on the flow required.

Makers: Teddington Industrial Equipment Ltd. **CPE 743**

Flexible heating cable

Complementary to the existing range of 'wind-on' flexible heating equipment manufactured by Electrothermal Engineering Ltd., the *Thermocord* braided heater is designed for all applications necessitating a heat-energy input where heating tapes or armoured heaters cannot meet the requirements.

The *Thermocord* consists of a pure nickel/chrome heating element insulated by inorganic fibres. Two feet of insulated, unheated, flexible lead is attached to each end of the heating section and the whole, including the unheated leads, is covered with a tough external sheath of braided glass fibre. Designed to operate with a loading of 5 watts/lin.-in., element temperatures up to 450°C. are attainable. The cable has an approximate outside diameter of $\frac{3}{16}$ in., and is available in a variety of lengths.

The versatility of this equipment can be judged from the fact that the 24-in. length, when close coiled round a 1-in. tubing gives a wattage concentration of 26 w./sq.in. Alternatively, it can be traced or spiralled round the tubing at any predetermined open pitch to give the required energy input. Where processes require observation, the *Thermocord*, used in conjunction with glass tubing, will provide the ideal solution. Applications extend to all vessels irrespective of shape, size or material. **CPE 744**

Resistant coatings

A series of zinc-rich coatings for atmospheric, marine and chemical plant protection has been announced in the U.S.

The manufacturers, in their formulating, claim that they were able to lower the zinc content and increase the binder strength. This is stated to provide tougher, tighter and better bonding than the older types of zinc coating developed in Europe. Test results show that the heavy thickness of these *Carboline* zinc-rich coatings (6 mils per coat) provide at least twice the life of thin 2-mil zinc materials. As an example, accelerated tests in aerated brine over 18 months old indicate an estimated life of more than 10 years in immersion service. **CPE 745**

World News

POLAND

Polish sulphur production

According to a report issued by the East German News Agency A.D.N., Poland has hopes of becoming the second largest producer of sulphur in the world after the U.S. by 1970. Construction of a plant on both banks of the Weichsel River near Rarnobrzeg and Piaseczna is due to start with Czech assistance later this year. Geological surveys in the area have shown that sulphur reserves were about 95 million tons.

PERU

Fertiliser plant's progress

It is now estimated that the fertiliser plant of Fertilizantes Sinteticos S.A. will be inaugurated towards the end of 1958. The construction of the factory, near Callao, is in progress. The initial annual output planned is as follows: 25,000 tons of ammonium nitrate for agricultural use and 5,000 tons for industrial use (explosives), 1,500 tons of concentrated nitric acid for explosives, 15,000 tons of ammonium sulphate for agriculture, and 1,000 tons of ammonium anhydride.

PORTUGAL

New companies

Two new industrial enterprises, one for the production of ammonia gas for lighting and the other for nitrogenous manures have been created. The first, called Sociedade Portuguesa de Petroquimica, capitalised at 120 million escudos, will extract gas and ammonia from the waste products of the Sacor oil refinery near Lisbon. Sacor is the main shareholder of the new company with C.U.F. and Compagnies Reunis de Gaz et Electricite as other shareholders.

The second company, called Sociedade Nitratos de Portugal, is capitalised at 70 million escudos and once again Sacor is the main shareholder. This company will produce, distribute and market nitrogenous and ammonia fertilisers.

ISRAEL

Industrial developments

Textile expansion will centre on the rayon factory planned for Ashdod-Yam. This concern will provide raw material for many other textile plants. Investment and output in the paper and pulp industry will more than double in the next five years. This industry, which today produces paper, cardboard boxes and other paper containers, will be increased by a pulp factory utilising corn and cotton stalks, thus enabling a considerable reduction in the import of pulp. The paper and cardboard plants will also double their capacity in the next few years.

Similar plans are outlined for the leather chemicals, ceramics, glass, building materials, food, wood, printing and diamond-cutting and gem industries.

Fertiliser supply

All Israel's requirements of fertilisers are now provided by the plant of the Fertilisers and Chemicals Ltd., at Haifa, and the company expects to export $1½ million worth of fertilisers this year. Last year's exports totalled 13,000 tons, of which 7,000 tons were ammonium sulphate, 1,500 dicalcium phosphate, and 4,500 tons potassium sulphate.

The plant was described in CHEMICAL & PROCESS ENGINEERING, 1956, **37** (7), 235.

INDIA

Polystyrene

The polystyrene plant of Polychem Ltd., set up with the help of the Dow Chemical Co. with a processing capacity of 10 million to 12 million lb. and a present finishing capacity of 6 million lb., commenced production recently.

SOUTH AFRICA

Gas producers called for

The Stores Department, South African Railways, is calling for tenders for the supply and erection of suitable gas producers including all necessary instruments, controls, recording devices etc. gas-cleaning units, desulphurising plants, cooling towers, settling sumps or tanks for process water from the gas cleaning plant, coal-handling plant and storage bunker, ash-handling plant and storage bunker, gas analysers, mechanical stokers, air blast saturation temperature controller and any additional equipment necessary for the proper functioning of the plant. The closing date is January 31, 1958. Further information can be obtained from the Board of Trade, Export Services Branch, Lacon House, Theobalds Road, W.C.1, quoting ESB/21333/57.

JAPAN

Polystyrene production

Monsanto-Kasei Chemical Co., one of the two polystyrene producers in Japan, has announced that it would more than triple its production capacity of polystyrene plastics, to 1,000 tons monthly by September 1958, from the present 300 tons. At present, the Asahi-Dow Chemical Co., the other producer, is producing polystyrene at a rate of 400 tons monthly.

Export of magnesium

Japan will shortly start to export primary magnesium under a trial contract with Communist China.

The Furukawa Magnesium Co., the sole magnesium refinery in Japan, said it had concluded a contract with Peking for the export of seven tons of primary magnesium containing 99.97% of magnesium in barter with fluorite from Communist China. This will be the first export of primary magnesium produced in Japan since the end of the war. The export price has been fixed at £310/ton, c.i.f. Shanghai, the company says.

RHODESIA

Lime production

Plans to make the Rhodesian Federation self-sufficient in its requirements of hydrated lime will be taken a step forward with the opening of a new lime works at Shamva. Should the new plant fulfil expectations it is probable that it will be extended with the aim of supplying the whole of the Salisbury area.

MALAYA

Catalytic oil gas plants

The Singapore City Council has placed an order for three catalytic oil gas plants to produce gas from a heavy residual fuel oil. The new plant will increase the gas producing capacity by 50%, and reduce production costs. The Council is also planning to install a high-pressure ring main at a cost of $1 million to increase the present low pressure gas supply in the north central portion of the island. The gas works will also soon have new oil-burning equipment for its steam boilers.

NORWAY

Atomic power for industry

When the new Norwegian industrial atomic reactor at Halden—in East Norway, south of Oslo—opens at the end of this year, it will supply local pulp factories with 10,000 tons/day of steam. The annual consumption of steam for Norwegian industry is estimated at 10 million tons. Norway

is to buy 16 tons of heavy water in the U.S. and 8 tons of natural uranium fuel elements in Britain for her civilian atomic research. The total cost is about £500,000.

Nitrogen output

Output of nitrogen products by Norsk Hydro during the year 1957-58 is expected to total around 230,000 tons of N_2 equivalent, the firm has announced. This is roughly the same as last year. Nearly the whole of the year's production has already been sold.

IRAQ

Oil refineries

The Iraq Government have decided to convert the Qayyara bitumen refinery into an ordinary refinery plant producing 250,000 tons p.a. of ordinary petroleum products. The stated reason for the change is the growing need for oil products of all kinds throughout Iraq but it has been suggested that the type of local crude oil which Qayyara has so far been using is unsuitable for refining and that the refinery would do better on piped crude which it is now planned to send from Kirkuk.

It has also been decided to double the capacity of the Government Oil Refinery at Daura near Bagdad. Negotiations at the end of the month were well advanced between the Government and the builders of the original refinery who expect to finish work on the lubricating oil plant this autumn.

BRAZIL

Carbon products

A French company (Cie. de Produits Chimiques et Electrometallurgiques of Paris) is to establish in Brazil a factory to produce carbon products, including graphite and industrial electrodes. The factory will be set up in Jundiai, in the State of Sao Paulo. Initial production targets are 4,000 tons of graphite electrodes and 6,000 tons of paste.

FRANCE

Portuguese cement plant contract

The French heavy engineering company, Fives-Lille, has concluded a contract to build a cement oven with a daily capacity of 1,600 tons at Aliandra, near Lisbon. The company said that this represented the most important plant of this kind in the world. The contract provides that the plant must be completed within eighteen months.

THAILAND

Oil refining industry

It has been suggested that the Government are intending to set up a domestic oil refining industry, and a number of proposals have been made for erecting a refinery. There is still no finance for the Defence Energy Department's refinery project at Farng (or Fang) in the far north. Apart from this small scheme, there are a number of proposals for erecting a larger refinery in the Gulf of Siam, any one of which should suffice to meet the country's needs.

Thermal power plant

An agreement was signed recently by the Lignite Electric Power Organisation for the construction, with I.C.A. financial assistance, of a 10,000 kw. thermal power plant in Mae Moh to be run on lignite fuel from the adjoining mine. It was estimated that this plant will be able to supply power towards the end of 1960.

TRINIDAD

Nitrogen fertiliser plant

It is reported that the Government of Trinidad and Tobago and W. R. Grace & Co. have reached agreement on the establishment of a B.W.I. $19 million fertiliser plant in Trinidad. The Minister of Industry, Commerce and Tourism announced that W. R. Grace & Co. had been granted pioneer status for the construction of a complete nitrogen fertiliser plant. It was also reported that agreement had been reached to give the West Indies, British Guiana and British Honduras priority in the supply of ammonium sulphate and urea, fertilisers which are now heavily imported into the area.

SWEDEN

Oil refinery modernisation planned

The Johnson concern's oil refinery at Nynäshamn is to be modernised and its capacity is to be raised to 2 million cu.m. of crude oil p.a. The production of high octane petrol will be increased by over 100%. The work of modernising and increasing the capacity of the plant is to be carried out by Bechtel Corporation of San Francisco.

FINLAND

Rolling mills

Plans have been announced by the State-owned Otanmaki Mining Co. for the erection of a further steel works and rolling mill, with a capacity of some 100,000 tons of sheet steel p.a. to be doubled later. The location of the plant has not yet been decided but it will be erected in Northern Finland partly because of transport and partly for employment reasons. This company now produces 6% of the total world production of vanadium.

HOLLAND

Oil refinery extension

The Caltex Oil Co. announced that their refinery works in Rotterdam will be considerably extended in the next few years. The extension programme provides for the construction of new platforms for the platinum refining of petrol, the construction of a central laboratory in Rotterdam for more than 70% Caltex's affiliated companies in a number of Eastern hemisphere countries and projects for a new petrol harbour area near Rotterdam.

COLOMBIA

American chemical concerns' activities

Columbian Sun Oil, of Wilmington, Delaware, has opened an office in Colombia with a capital of Ps. 200,000. The company's object is the exploitation, sale and distribution of petrol and its derivatives. A Canadian firm has completed an extensive aerial exploration of the eastern and mountainous parts of Colombia on behalf of petrol interests.

UNITED STATES

Atomic reactors for export

Atomics International, a division of North American Aviation Inc., of Los Angeles, has won a number of European and Far Eastern orders for atomic reactors.

One research reactor, in 25 crates weighing up to 10,000 lb. each, has just been shipped from the port of Los Angeles for the Danish Atomic Energy Commission laboratory, 20 miles west of Copenhagen.

This reactor will be used for research and training in reactor operation, technology and physics, radio chemistry and the production of radioisotopes.

The American producer is also building reactors for Germany—for the University of Frankfurt and Farbwerke Hoechst A.G. in West Berlin. Yet another will be shipped from Los Angeles for the Japan Atomic Energy Research Institute near Tokyo.

A broad agreement has been signed recently between Atomics International and A.S.E.A. Co., of Sweden, for mutual licences on patents and constructions, and liaison on research and development in the atomic reactor field.

New Stauffer plant

Stauffer Chemical Co. plans to build another sulphuric acid regeneration plant at Hammond, Indiana, to process oil refinery sludge acids. It will have a capacity of 400 tons/day.

GREECE

Proposed power station

Plans are afoot for the construction of a further thermo-electric power station at Ptolemais, with a capacity of 100,000 kw. This is part of the Public Power Corporation's five-year plan, and the new station will service various new heavy industries in the area, such as the Larymna metallurgical concern, iron and nickel works, etc.

Lignite

Construction of the new lignite mine at Ptolemais, Western Macedonia, is well under way. Distribution of the mine's annual output has been estimated at one million tons for the Ptolemais 70,000 kw. thermo-electric power station now under construction by the Swiss firm, Brown-Boveri and Co., 600,000 tons for conversion into briquettes, and 300,000 tons for the Larymna metallurgical industry. Production will be stepped up when the larger power station is completed, and when the proposed nitrogen fertiliser factory at Ptolemais is ready.

ITALY

Polythene production

Edison and the Union Carbide have joined to form a new company, 'Celene,' for the production of high-pressure polythene. Initial production is expected to be at the rate of 10,000 tons p.a.

IRAN

Plastics and rubber industries

A German firm will shortly commence work on the construction of a plastics factory in Tehran, and another German firm is shortly to build a rubber goods factory near the capital.

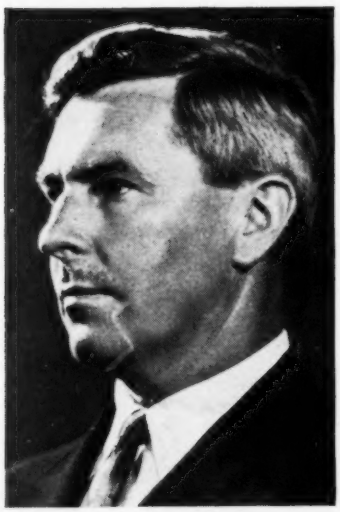
MEXICO

Titanium dioxide

Industrias Quimicas Basicas de Mexico S.A. is to build a titanium dioxide plant near the port of Vera Cruz; for this purpose they will receive technical assistance from the Glidden Co. of the U.S.A. Investment in the new plant will be 80 million pesos of which 55% will come from the Mexican company and Nacional Financiera, and 45% will be obtained from abroad in credits for equipment to be guaranteed by Nacional Financiera. The President of the new company is Dr. E. Szomlo, the founder and previous owner of Syntex S.A.

★ Personal Paragraphs ★

★ **Sir Leonard Owen,** C.B.E., director of engineering and deputy to the managing director of the Industrial Group of the Atomic Energy Authority, has been appointed managing director of the Industrial Group. He has been engaged in the development of Britain's atomic energy programme since 1946, when he was appointed director of engineering on the production side by the Minister of Supply. In the following year he became assistant controller in the Atomic Energy Division's production side. When the United Kingdom Atomic Energy Authority was formed in 1954, his title became 'Director of Engineering and Deputy Managing Director.'



Mr. H. McNeil

★ **Dr. L. G. Groves** has been appointed managing director of Davy British Oxygen Ltd. and relinquishes his appointment on the board of British Oxygen Wimpey Ltd.

★ **Mr. H. McNeil,** has been elected to succeed J. R. Rylands as president of the Institute of Fuel. He was born in New Zealand in 1904. Appointed an assistant engineer by the State Electricity Commission of Victoria, Australia in 1929, he was engaged in their Brown Coal Briquetting Department. He joined Babcock & Wilcox Ltd. in London in 1931 as a service engineer and was appointed engineer in charge of peat briquetting in 1935, deputy chief engineer 1938, general manager 1947, becoming a director of the company in 1950 and in 1953 deputy managing director. He is also a director of Dewrance and Co. Ltd. and of the German, Spanish and Australian Babcock & Wilcox companies, frequently travelling in Europe, Australia and New Zealand in recent years.

★ **Mr. James William Kendall,** who died suddenly at his home at Penn, Wolverhampton, aged 49, was one of the original team of 12 which was formed in February, 1946 to build up the production side of Britain's new atomic energy programme. Mr. Kendall, who had previously been working in Government ordnance factories with Sir Christopher Hinton and Sir Leonard Owen, was placed in charge of a pile design team which gained its first experience in building the large experimental pile known as BEPO at Harwell. They then designed and built the two reactors at Windscale Works in Cumberland which have been operating as plutonium producers since the end of 1950. Mr. Kendall's next task was to design the fast reactor which is now nearing completion at Dounreay in the north of Scotland, and he was engaged on this task until April 30, 1956, when he left the United Kingdom Atomic Energy Authority to join the firm of John Thompson at Wolverhampton.

★ **Mr. J. Westhead** has been appointed works superintendent of the Silvertown Rubber Co. Ltd. A new technical manager, **Mr. W. Lessing,** has also been appointed.

★ After nearly 52 years' service with Price's (Bromborough) Ltd., **Mr. Robert Eaton,** the manager of their fatty acid department has retired. He joined the company in 1905, and his retirement can be said to have marked the end of an era, since only recently Price's announced the closing of the old pressing process for the manufacture of oleines and stearines—a process with which he had been associated for many years. Price's oleines and stearines are now produced exclusively by the *Emersol* process of solvent separation.

Technology Notebook

More chemical engineering students for Loughborough

Plans are under way at Loughborough College of Technology to provide a considerable expansion in chemical engineering facilities. The present floor space, which is in buildings located on a temporary site, is being doubled to provide over 8,000 sq. ft. of lecture room and laboratory space, which will be in use next session. Further increases in space are envisaged when the department moves to new buildings in about three years' time.

The greater part of this expansion is to provide for the greatly increased numbers of students on the full-time course. In addition, facilities are being provided for a new sandwich course, which is to commence early next year. This will be a dual or two-tier sandwich course, with an intake of two groups each year, one group being at the college whilst the other is in industry, thus minimising any dislocation of the personnel arrangements of any company sending students.

Non-destructive testing

The Institute of Physics has issued some notes on the 'Non-destructive Testing Conference' to be held in Chicago from November 4 to 8, and it is planned to devote the first two sessions of the conference to a critical analysis of the existing limitations of non-destructive testing. Limitations regarding the appreciation and acceptance of non-destructive testing by potential users should be discussed as well as limitations regarding the technology (including standardisation) of this field. The third session will be devoted to a discussion of recommendations or suggestions for overcoming these limitations.

Chemical Society research grants

The Research Fund of the Chemical Society provides grants for the assistance of research in all branches of chemistry, about £700 p.a. being available for this purpose. Applications for grants will be considered in November and should be submitted on the appropriate form not later than November 14, 1957.

In addition, applications are being invited from citizens of any country within the British Commonwealth for the Corday-Morgan Commonwealth Fellowship. This will be awarded for post-doctorate (or equivalent) study in any branch of chemistry. The value of the fellowship will be £700 p.a. and it will be tenable for one year in some part of the British Commonwealth other than that at which the candidate received his scientific education.

Research scholarships

The Gas Council awards each year five research scholarships to students who have recently graduated in physics, chemistry or engineering. Scholarships are being awarded this year to Mr. A. Richmond (University of Oxford, Department of Inorganic and Physical Chemistry), the subject being the mechanism of gaseous oxidation processes; Mr. K. J. Reid (University of Cambridge, Department of Chemical Engineering), chemical engineering fundamentals; Mr. P. Hawtin (University College, University of London, Department of Chemical Engineering), heat transfer with a special interest in heat transfer to gases; Mr. D. Wilson (University of Birmingham, Department of Chemical Engineering), gas absorption; Mr. J. N. Sherwood (University of Glasgow, Department of Chemistry), diffusion studies in molecular crystals.

The Leonard Hill Technical Group—October

Articles appearing in some of our associate journals this month include:

Manufacturing Chemist—Synthesis of Alkyl Halides; N-Oxides of Pyridine and its Derivatives; Progress Reports on Analytical Chemistry, Cosmetics and Toilet Preparations, Pest Control.

Atomics — The Halden Project (Norwegian Power Reactor); The Wetting of Solids by Liquid Metals; Physical Properties and Alloying Behaviour of Plutonium; Reactivity Changes.

Automation Progress — Automatic Equipment Produces Electric Motors; Infra-Red Absorption for Process Analysis; Share Registration by Punch Card System; Transfer Press Assembly Welds Car Wheels.

World Crops—Mechanisation of Tree Food Crops; Resistance to Mechanisation; The Agricultural Engineers Association.

Corrosion Technology—Metallic Surfaces Research; Preview of the Corrosion Exhibition; Corrosion Research Laboratories; Testing Establishment; Corrosion Research: Methods of Protection; Abstracts of Corrosion Convention Papers.

Paint Manufacture—N.P.I.R.I. Standard Test Method for Pigment Identification; Chelatometric Method for the Analysis of Lithopone; Storage Stability of Polyvinyl Acetate Emulsion Paints; Snags in Technical Translations.

High polymers conference

A conference on high polymers will be held at Nottingham University from July 21 to 24, 1958, under the auspices of the Macromolecular Commission of the International Union of Pure and Applied Chemistry; it is being organised by a British committee under the chairmanship of Dr. H. W. Melville, F.R.S., Secretary of the Department of Scientific and Industrial Research. The conference will have two main themes: (1) Reaction mechanism and kinetics, and (2) physical, thermodynamic and mechanical properties.

MEETINGS

The Fertiliser Society

October 22. 'Fertilisers and Productivity' by David Lowe, Lecture Hall of the Geological Society, Burlington House, Piccadilly, London, W.1.

Incorporated Plant Engineers

October 14. 'Boiler feed systems and auxiliaries,' by J. R. Cairns, 7.30 p.m., Mathers Hotel, Leeds.

October 28. 'Thermoplastics, with Particular Reference to their Application in Tube Manufacture and Usage,' by J. Aldred, 7.30 p.m., Leeds University.

Coal Preparation Plant Association

October 21 to 25. Second Symposium on Coal Preparation, The University, Leeds.

INTERNATIONAL CONFERENCES

October 14-18. International Industrial Development Conference, San Francisco, California.

October 21-25. Second Symposium on Coal Preparation, The University, Leeds, England.

November 2-8. Second World Metallurgical Congress, and

November 3-8, 2nd International Conference on Non-destructive Testing; Chicago, Illinois.